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Choe Sang

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Biology of the Japanese Common Sea Cucumber

Stichopus Japonicus Selenka

Choe SANG, 1962

Preface

The sea cucumbers of the eastern waters have successively been described from around 1860 to the early 20th century by E. Selenka, C. Semper, E. von Marenzeller, H. Ludwig, H. Théel, C.P. Sluiter, K. Mitsukuri and others, and the taxonomy has been established.

As for the Japanese sea cucumbers, the studies by Mitsukuri (1912) provided a system and a base for taxonomic research. Further advances were made through the studies of Oshima (1915, 1918) and so was reached the present-time state of knowledge.

Up to about 100 types of sea cucumber were known in the neighboring seas on the old maps of Japan. Of these 14 or 15 species were used by the industry. However most came from the southern waters. At the

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present time, there are only 3 edible species produced in the Japanese coastal waters viz. "manamako" (Stichopus japonicus Selenka, "kinko" (Cucumaria japonica Semper) and "okinamako" (Parastichopus nigripunctatus - Augustin). Of these, manamako is the most harvested. For a long time it has among the important fisheries products been regarded as the typical edible sea cucumber.

Manamako is widely distributed. The vertical distribution extends from the low tide zone to the upper shallow pelagic zone with a depth of 20 - 30 m. Its horizontal distribution along the North Pacific coast extends to entire coastal areas of Sitka in Alaska, Sakhalin, Hokkaido and the entire Sea of Japan coast. In the centre coastal Pacific waters, it is distributed in almost all coastal waters off Kyushu but not off the southern coast of Shikoku. On the Yellow Sea side, it is found in the northern part of the Bohai Bay.

Manamako is generally used as raw food. The boiled, cured and dried body walls were used to make "kaisen". This together with dried abalone and shark fins was once one of the so-called three goods in straw bags, and was from old a valuable commodity in the trade with China. The alimentary canal and respiratory tree (water lung) pickled in salt makes "konowata" and "minowata". The raw-dried ovary makes "konoko". All these products are considered to be delicacies and are widely appreciated. Manamako is thus used entirely without anything being wasted.

In this perspective, the study of manamako was important from an economic viewpoint. In response to such demand, Mitsukuri was the first to study the ecology and growth of manamako. All kinds of further studies were made later. Tokuhisa (1915) studied the general ecology, Isono the alimentary canal regeneration, Kikuchi (1937) the reproduction, Inaba (1937) the early development, Kinoshita - Shibutani (1939) the spawning periods, Kinoshita - Tanaka (1939), Yamauchi (1942) the diet, Imai - Inaba - Sato - Hatanaka (1950) the artificial rearing of larvae, Tanikawa et al (1953 - 1955) the nutritive value of sea cucumbers and the changes in somatic components after death, and Tanaka (1958 a, b) the seasonal changes in the gonads and in the digestion. 2

The study of manamako ecology is the most important matter in order to establish the multiplication measures and methods. It is however difficult to find satisfactory information on this point in the studies conducted so far. This is why, using the study results of the former scholars, we made a new study of the overall morphology and ecology. We considered as separate taxonomic populations the aonamako (green sea cucumber) which prefers to live in inner bays and areas made of sandy mud on the one hand and the akanamako whic prefers to live in the outer sea among reefs and sunken rocks, which so far had been treated as one single species, and we were able to discover a few new facts about their ecological characteristics.

As for the method of manamako multiplication, methods such as restricting the harvesting periods, forbidding harvesting in some areas and

rotating harvests have been practiced for a long time. There were other methods such as releasing parent manamako and establishing stone shelters. Unfortunately the results were not too satisfactory because of the insufficiency of important biological, ecological information.

It seems that the main purpose of releasing parent namako is to obtain a production of larval namako. However in the multiplication of the larval namako, one neglected to foster environments ecologically well suited to the young namako, which entailed necessarily unsatisfactory results.

One should make a clear distinction between releasing manamako for the purpose of increasing the number of young namako on the one hand and intending to increase the weight of the released namako themselves on the other. When the purpose is to increase the weight it is effective to use small individuals whose rate of weight increase will be great. In this connection, we showed that by using the regenerative power of namako, it is possible to reuse the alimentary canal during 1 fishing period, and that by dropping the larval individuals back in the fishing grounds after using the above organ, a great contribution would be made to the renewed production in the following year, and we were able to provide clear confirmation of these facts on an operational scale.

The present book researches and discusses important questions of morphology and ecology from the viewpoint of basic information for green and for red sea cucumber multiplication, although it leaves numerous

questions regarding multiplication to be clarified. As we are confident 3
that this study is to a certain degree contributing to the establishing of a base for green and red sea cucumbers multiplication and to the determining of appropriate measures, we report here comprehensively the results of the studies conducted so far.

At the start of the present work we wish to express our profound gratitude to Professor Yasuo OSHIMA who provided the topic of the present research, gave us frequent advice and encouragement. We are also grateful to Dr. Nakaroku NAKAMURA, Head of the Freshwater Fisheries Research Center who gave us useful advice and allowed us the use of convenient research facilities.

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Part II - Studies on the ecology of the green and the red sea cucumbers 17

Introduction

Manamako occupied from old an important position in Japan as one of the important fisheries products. Various multiplication methods have suddenly been taught and studied. However, surprisingly there are no studies in the field of ecology even though ecology should be the very base for multiplication.

Mitsukuri responding to the wishes of the Ministry of Agriculture and Commerce of the time, conducted from 1893 to 1897 studies on the life habits and life history of manamako, mainly at locations in Kanazawa and Misaki in the Kanagawa Prefecture. Later, Tokuhisa (1915) published articles devoted to the growth, aestivation, spawning period, bottom sediments, diet of manamako in the Nanao bay of the Noto peninsula. These two articles have made figure of classics with regard to the ecology of manamako. Isono (1929) reported on the regeneration of the alimentary canal, Inaba (1937) on artificial insemination and Kinoshita - Shibutani (1939) on the spawning season of manamako in Hokkaido. Kinoshita - Tanaka (1939) made quantitative studies of the diet of manamko in Hokkaido. They discovered that the alimentary canal is mainly filled with grains of sand and with mud and found detritus, plankton, protozoa as well as shells, fish eggs, gastropod larvae and algae fragments and such in the same organs. Yamauchi (1942) reported finding no diurnal characteristics in the feeding

activity of manamako. Tanaka (1958 a, b) reported on the seasonal changes observed in the gonads of green sea cucumbers of Hokkaido, on their feeding and digesting times. Sang - Oshima (1961) published study results on the ecological differences between the green and red sea cucumbers.

Numerous studies have been conducted abroad about the morphology, development, regeneration and physiology of the sea cucumbers. Since sea cucumbers are not used as food, the studies contain few economical considerations.

In these circumstances, we wanted to base ourselves on the scholarly achievements of the past authors and to remedy the existing insufficiencies. Moreover, pointing toward further developments we studied the living environment of the green and of the red cucumbers, their 18
resistance to salt, the seasonal variations in the volume of oxygen consumption, of the alimentary canal, and in the volume of respiratory tree. We also studied reproduction, diet, the digestive oxygen, the growth, the regeneration and aestivation, and obtained basic data for reproduction. Our study results are explained hereunder.

Chapter 3 - Measurements of the green and the red sea cucumbers 32

Past manamako measurements were based on body length and total weight. However, the bodies of the green and red sea cucumbers elongate and shrink conspicuously. The universality of the body measurement values is poor with regard to reproduction. Moreover, depending on the variations in the quantity of feeding accompanying the seasonal changes in alimentary canal and respiratory tree volumes and such, and because of the variations in the volume of water staying inside the respiratory tree, the body weight measurements based on total body weight vary greatly, and it cannot be said that the standard quality of the norms for measurements is satisfactory. So, in order to eliminate these defects, we cut the body open and adopted as new measurement character the weight of the body walls from which the alimentary canal, respiratory tree and caeliac water had been removed (abbreviated hereafter as body wall weight).

The measurements of the body length, total body weight and capacity were performed under the following conditions. We left the sea cucumbers in tanks of running water or left them free of any inconvenience. After a short time the sea cucumbers display a shape close to the natural shape. Picking them up swiftly, we measured their length. We made them disgorge the excess water staying inside the respiratory tree, and measured the entire weight and the capacity.

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A - Measurement errors of the body length, the total body weight and the body capacity

We chose 16 large and 16 small green and red sea cucumbers whose shape was close to the natural shape, measured 5 - 7 times in a row the body length, total body weight, capacity, and finally cut the sea cucumbers open to measure the weight of the body wall. The error in the measurements of the body length, total body weight and capacity are shown in Tables 4, 5.

The standard deviation in the measurements of the body length of the green sea cucumber was 0.21 - 2.09, and the coefficient of variation was 2.9 - 14.8% (average of 7.3%). The individual differences were great. The error in measurement value was 0.6 - 9.5% (average of 4.81%). One must say that the random error in measurement character is fairly large. 34

The standard deviation in the capacity measurements was 0.82 - 40.46, the variation coefficient was 1.0 - 11.2% (3.3%) and the error in measurement value was 0.7 - 9.2% (2.91%). The error was smaller than in the body length measurements.

The variation coefficient in the measurement values of the total weight was 0.8 - 10.6% (2.8%), the error was 0.7 - 8.6% (2.40%). Of the 3 character errors, the present error was the smallest.

The variation coefficient in the red sea cucumber body length measurements was 4.9 - 43.7% (13.0%), the error reached 1.4 - 19.1% (5.13%) and was fairly larger than with green sea cucumbers. 35

The variation coefficient in the total weight measurement values was 1.9 - 15.1% (5.2%) and the error was 0.7 - 5.4%. The error in body length, total body weight measurements was greater with read sea cucumbers than with green sea cucumbers. The reasons seems to be that red sea cucumbers extend and shrink more than green sea cucumbers do. 36

The measurement error concerning the green and red sea cucumbers is not seen to be directly related to the size of the individuals. The error in the body length measurements is based on the expansion and contraction characteristics. The errors in capacity and total weight seem to be due to the level of residual water inside the respiratory tree. More particularly, the body length may vary by 100% or more according to the contraction and elongation times. The total body weight and capacity are expected to vary considerably according to the seasonal weight variations of the alimentary canal and of the respiratory tree and according to the accompanying changes in volumes of food ingested. When measuring the body length, capacity, total weight it is necessary to pay close attention to these error characteristics.

B - Relations of the body length to the total body weight and to the body capacity

Fig. 10 shows the correlation between total body weight (TWg) and capacity (Vcc) on the one hand and of body length on the other of 240 green sea cucumbers of a 2.25 cm body length range captured in Nisaki and Fukue, Atsumi peninsula, Aichi Prefecture. These correlations are indicated in index curve. In both the relations between total body weight - capcity and body length one notes inflection points in 2 places, that is, 6.0 cm and 16.0 cm. The relational equations of these correlations are shown in Table 6. It is surmised that the inflection points are related to multiplication, aestivation and growth.

C - Relation between the total body weight and the body capacity

The correlation between capacity (Vcc) and total body weight (TWg) is the primary equation shown in Fig. 11. 37

With the 240 individuals collected June 3 - 6, 1955, in Nisaki, Fukue

$V = 0.9620\ TW$

With the 270 individuals collected August 12, 1955, in Ehima,

$V = 0.9819\ TW$

With the 32 individuals collected November 4, 1955 in Ikawazu

$V = 0.9849\ TW$

The results are similar. The comprehensive relational equation 38 is expressed as $V = 0.9738\ TW$.

D - Relations of the weight of body wall to the total body weight and to the body capacity

Allometric correlations between total body weight (TWg) and body wall weight (MWg), capacity (Vcc) and body wall weight are assumed. In fact, such correlations apply well and may also be expressed by a simple primary equation. Graph 12 shows the correlation between the total body weight and body wall weight, and Graph 13 shows the correlation between capacity and body wall weight. Table 7 shows comprehensively the constants of these relational equations. According to these data, both the total body weight and the capacity show a clearly discontinuous part in the straight line where the body wall weight is 24 - 28g in August (Ehima), and show an inflection where the body wall weight is 70g. With the November (Ikawazu) and May (Momotori, Mie Prefecture) materials too, one notes an 39
inflection point there where the body wall weight is 25g. It is surmised that the discontinuation parts and inflection points on these straight lines are related to multiplication, aestivation, growth and such.

E - Relation between the weight of body wall and the amount of coeliac water

Fig. 14 shows the correlation between the amount of coeliac water and the body wall weight of green and red sea cucumbers. One notes rectilinear relationships between the logarithms of the volumes of coeliac water (CW cc) and the body wall weights (MWg).

With the green sea cucumbers collected in Momotori, February 1957, we have log CW = 1.3253 log MW = 0.9160. 41

With the red sea cucumbers, one notes the log CW = 1.3277 log MW = 1.1617 relational equation. With the green sea cucumbers collected November 1959 in Ikawazu, one notes the log CW = 1.0421 log MW = 0.3854 relational equation.

The volume of coeliac water in the green sea cucumbers varies in the 20 - 85% range vs. the body wall weight. The average is 51.3%. With the red sea cucumbers, the range of variation is 14 - 51%, and the average is 31.8%. The volume of coeliac water is smaller in the red sea cucumbers.

Chapter 4 - Habitat and environment

Mitsukuri (1896, 1912) touched on the habitat of manamako. Tokuhisa (1915) wrote about the relationship between the manamako living and the water temperature, bottom sediments. Sang - Oshima (1961) wrote about the relationship between the habitat and distribution of the green, red sea cucumbers on the one hand and the salinity and bottom sediments on the other. Yet, there are no detailed reports about the living environments of the green and red sea cucumbers as wholes.

As explained earlier, the green and red sea cucumbers are distributed over wide horizontal geographical zones. As for the vertical distribution, the green sea cucumber habitat extends from the coastal tidal zone to the purely muddy sediment zone with depth of 15 - 20 m. The habitat of the red sea cucumber extends from the coastal reef zone to the pebble, gravel zone. The zones of habitat are thus narrowly limited.

The environmental factors closely related to the habitats of the green and red sea cucumbers are the water temperatures, salinity, tidal currents, bottom sediments, food, the presence or absence of places where the larvae may settle. It seems that the most important elements determining the habitat distribution of both types of sea cucumbers are more particularly the 3 conditions of water temperature, salinity, bottom sediments as well as the presence or absence of places where the larvae are able to settle.

Yamauchi (1941) stated regarding the sea cucumber from Palau that the factors determining the living distribution are not necessarily simple, that first the water quality and then the diet are determining. He was of the opinion that the state of water quality in pelagic areas was to be judged on the basis of the state of sea cucumber distribution.

Generally pebbles, gravel, sand and sand-mud bottom sediment zones connected to coasts, inner bay reefs, and seaweed field zones not strongly affected by land water constitute good habitats for the green and

red sea cucumbers. However, open areas without places where the larvae can settle are rarely sea cucumber habitats.

Considering in the Aichi Prefecture the approximate 9,000,000 m² fishing grounds constituted by Ikawazu, Ehima, Uzue at the Atsumi peninsula 42
where there are several sites of sea cucumber production, we will discuss the correlation between habitat distribution and environmental factors such as habitat depth, water temperature, salinity, volume of dissolved oxygen, bottom sediment composition, volume of organic carbon and nitrogen in the bottom materials, and give the results obtained by examining the total amounts of population living in the said fishing grounds computed on the basis of sea cucumber fry presence and other quantitative habitat elements.

Materials and methods

During the 5 years from 1953 to 1957, the water temperature and salinity data were prepared by the Fisheries Experimental Station of the Aichi Prefecture and by the Ise Bay branch of the Fisheries Experimental Station of the Mie Prefecture on the basis of samples collected in the Mikawa bay, Irago waterway, off Atsumi, off Shinmaiko (Chita peninsula, Aichi Prefecture), Goza (Shima, Mie Prefecture). We based ourselves on the regular marine measurements performed to survey the sardine stocks and on the regular measurements performed in the Ago bay by the Fisheries Experimental Station of the Mie Prefecture for pearl cultivation.

As Fig. 15 shows, one surveyed on May 4 the water temperature, 43
chlorine volumes, dissolved oxygen volumes, bottom sediment compositions, organic carbon and nitrogen in the bottom sediments of 28 sites established at fishing grounds in Ikawazu, Ehima and Uzue.

The ordinary methods were used to measure the depths, water temperature, volume of chlorine, volumes of dissolved oxygen. For the bottom sediments we used a Sk-type mud collector. We classified the granular compositions of the bottom sediment with a Marukawa-type sand mud selector and prepared records by the same Marukawa method. For the volumes of organic carbon and total nitrogen in the mud sediments, we made determinations, using separately air-dried and filtered samples of 0.5 mm. We used the Dūrin* method for the carbon and the microkjedahl method for the nitrogen.

For the green sea cucumber distribution and volumes of population in the respective fishing grounds, we focused on the various sites investigated at the time of the aforementioned marine observations, on November 24 just prior to the lifting of the 1956 ban on sea cucumber harvest. We based ourselves on the numbers of green sea cucumbers which we were able to collect by dragging a net for 100 m in parallel to the coastal line. We used the sea cucumber beam trawl commonly employed in the same region (opening: 3 m). As shown in Fig. 15, we estimated the total population by converting to area divisions.

* translator's note : transliterated Japanese phonetic rendering of uncertain foreign name

A - Fishing ground environment and bottom sediments

The results of the fishing grounds investigations are consolidated in Table 8. The green sea cucumber fishing grounds in those places are formed at depths of not more than 15 - 17 m. The isobath (Fig. 16) follows roughly the coastal line. The distribution of the temperature (Fig. 17) and of chlorinity (Fig. 18) of the lower strata waters is closely 45
related to depth.

The early May water temperature is in the 15 - 17°C range, and higher along the coasts than in the offshore waters. The chorinity is within the 16.60 - 16.80% range and lower along the coast.

The volume of dissolved oxygen (Fig. 19) and its degree of saturation (Fig. 20) are 4.60 - 6.70 cc/L in a 77 - 115% range. The sites 1 - 6 show relatively low values because of the closeness to the mouth of the Fukue Bay (4.60 - 5.80 cc/L, 77 - 92%), and sites 15, 22 - 26 show the highest values among all fishing grounds concerned (5.80 - 6.70 cc/L, 99 - 115%).

Table 9 shows the grain compositions of the bottom sediments at the various sites. Fig. 21 is a sketch map based on these results and on the external appearances of the bottom sediment. As Fig. 21 shows, the bottom matters at the concerned places is closely related to the depth. In the low coastal waters, rocky reefs and seaweed field zones are progressing. Beyond these one reaches the pebble, gravel, sand,

sand-mud zone. In the deep offshore sites, one finds progress of the pure mud zone. As the sea bottom is flat without any obstacles, it makes for fishing grounds where the use of small sailing trawls is easy. Fishing sea cucumbers is operated by zones progressing from the coast to the pure mud sediments of the offshore waters. Almost no sea cucumbers are observed to live in the pure mud sediment zone of the offshore waters.

Figs. 22 and 23 show the distributions of the volumes of organic 50
carbon and total nitrogen (both in mg) contained in 100 g of dried bottom soil. One notes a close relationship between depth and bottom sediment composition.

The carbon and nitrogen contents in the gravel or sand-gravel bottom sediment zone were in the 0.4 - 0.6%, 0.03 - 0.05% ranges respectively. In the sand-mud zone they were 0.6 - 0.7%, 0.04 - 0.07%, and in the mud sediment zone 0.9 - 2.5%, 0.09 - 0.20%. The amount is generally lower in shallow waters and greater in deep waters.

B - Relation between the biomass and environmental factors.

Fig. 10 shows the size and the collected volume of green sea cucumbers caught by dragging for 100 m a sea cucumber beam trawl of 3 m opening, with the focus on the various investigation sites, at the end of November just before the lifting of sea cucumber fishing prohibition of 1956. As the beam trawl was operated by well trained specialists, the results would seem to constitute sufficiently reliable data for estimating

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the distribution and population of green sea cucumbers in the concerned fishing grounds at the time of the 1956 fishing season.

Stations 6, 7, 13, 14 and 21 are located in the pure mud sediment zone (Figs. 15, 21) and the sea cucumber population is almost nil. The zone containing the sites 15 - 17 and 22 - 25 is the zone with the largest sea cucumber population inside the fishing grounds. The investigation results agree with the views of most fisheries operators.

The area containing stations 15 - 17 and 22 - 25 where the population is dense contains good coastal reefs on which the sea cucumber fry settle well, and seaweed fields. The bottom sediments are made of sand and gravel or of sand. The zone is estimated to be endowed with good sea water circulating well and containing much dissolved oxygen.

The zone containing sites 9, 10, 11 shows a bottom sediment composition made of pebbles, sand and gravel. It is the zone where we obtained the highest rate of red sea cucumber mixed capture, using tow nets. The proportion rose as high as 10 - 12% (Fig. 7). The pebble bottom sediment suited to red cucumber habitation extends considerably far inside the offshore waters.

Thus is the green cucumber widely distributed in the pebble, gravel, sand, sand-mud sediment zones but not in the pure mud sediment zone. The population is large in those zones with strong seawater currents and with good contents of dissolved oxygen.

On the base of the numbers of individuals caught at each station, we show in Table 10 the numbers of individuals as converted to the areas of the various sectors. If, setting the capture rate of sea cucumber beam trawl at 0.5* we multiply by 2 the total numbers of individuals in 52
Table 10, we have the entire population of the concerned fishing grounds at the beginning of the 1956 fishing season. On this base, the total number of green sea cucumbers that could be targeted for fishing in the year is about 630,000. The total weight is estimated to be about 6,600 kg. This represents a population density of 1 individual per 14.3m².

C - Size gradation in the green sea cucumber based on the water depth

The green sea cucumber size distribution in the fishing grounds concerned is noted to be closely related to depth. The depth-depending changes in average weight of the green cucumbers gathered in fixed quantities at the various investigation sites (Table 10), indicate a clear stratification of green sea cucumber sizes depending on the depth.

On the basis of the results shown in Table 10, we show graphically in Fig. 24 the relationship between water depth and sea cucumber size. It is shown that the individuals with a total body weight

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*Note: According to the words of the fishermen experienced in catching sea cucumbers in the areas concerned, a sea cucumber beam trawl fishing rate of 0.5 is not exaggerated.

(average value) of 50 g or less are distributed in the shallow places near the coast. Those of 50 - 100 g are distributed at a depth of 5 m or less. The 100 - 150 g individuals are distributed in the 5 - 10 m depth range, those of 150 - 200 g in the 10 - 15 m depth range, and the large sea cucumbers of 200 g or more are distributed at a depth of 15 m or lower.

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The above results are expressed in average total weight. The body wall compositions of the green sea cucumbers gathered on June 2, 3 of 1957 at every separate depth in the fishing grounds concerned are shown in Fig. 25.

In the tidal zone, the body wall weight range is 2.5 - 22.5 g 54
(average: 9.6 g), in the seaweed fields it is 12.5 - 42.5 g (25.0 g), at the 4.5 - 6.0 m water depth it is 17.5 - 102.5 g (45.8 g), at the 9.0 - 10.5 m water depth it is 37.5 - 207.5 g (87.9 g), at the 12.0 - 13.5 m water depth, it is 102.5 - 187.5 g (150.0 g) and at the 13.5 - 15.0 m water depth, it is 122.5 - 232.5 g (180.6 g). The sea cucumber size shows some scattering. Yet, the sea cucumber size increases together with the depth.

It is not certain that such obvious phenomenon is also seen in the green sea cucumber fishing grounds of other regions. However, no large sea cucumbers are seen at all in shallow places. Conversely, no small sea cucumbers are seen in deep places. This is one important specific point in the green sea cucumber ecology.

Meanwhile, a similar phenomenon is observed with regard to the red sea cucumber. In its relatively narrow vertical distribution range, the sizes increase together with the depth.

So, how did the green and red sea cucumbers' depth-based stratification occur? Depth is closely related to the structure of the bottom sediments. As the depth increases, there is more muddy sediment, and generally there is also more organic carbon and nitrogen in the bottom sediments. Consequently, as the depth increases, more organic carbon and nitrogen is ingested by the sea cucumbers, and one may say that somehow the depth-based sea cucumber size stratification is an ecologically adapted phenomenon.

It is assumed that the distribution of the after-mentioned sea cucumber fry is limited to the shallow places near the coast, and that after the larval period around the place of settlement they move gradually toward the offshore waters as they grow. However, as the aestivation phase suggests, one may assume that depending on the sea cucumber growth stage there are changes in the degrees of physiological adaptation to the water temperature and to the amounts of sunlight. More particularly, with regard to water temperature, there is concomitant to growth an increasing tendency toward narrowing temperature characteristics. During the period from late spring to early summer when the temperature rises, there is a movement toward deeper place which provide more stable temperatures. This seems to be one reason for the occurrence of size stratification based on depth. We will explain this in further details in the chapter on aestivation.

D - Relation between salinity and distribution of the green and the red sea cucumbers

Sang - Oshima (1961) made detailed reports about the distribution of the green and the red sea cucumbers along the costs of the Aichi and Mie 55
Prefectures (1961) and stated that red sea cucumbers live inside bays while the green sea cucumbers live in the outer sea. Shinmaiko on the Chita peninsula, Aichi Prefecture is the limit of the green sea cucumber distribution on the eastern coast of the Ise Bay. It seems that the region north of Shinmaiko is affected by the land waters of the Kiso river waters system. Yet, one sees no green sea cucumber distribution. Generally green sea cucumbers are strongly present in the Mikawa bay, Atsumi bay coastal zone. Almost nothing but red sea cucumbers are found around Kamijima, Toshi, in the Irago waterway around Goza at the mouth of the Ago bay. In the region east of Waji of the sea outside Atsumi there are no sea cucumbers maybe because of the open industrial location conditions.

We thus established Shinmaiko as the limit of the green sea cucumber habitat and considered the Mikawa bay as the site with a strong green sea cucumber presence. We consider the Irago waterway and Goza as the site with a strong red sea cucumber presence, and established the sea outside Atsumi as the purely outer sea salty limit of its population. On the basis of the monthly water temperatures, chlorinity changes of the surface and of the 10 m strata in five years from 1953 to 1957, we discussed the range of the red and of the green sea cucumbers adaptation to salinity and more particularly to water temperature.

Fig. 26 shows the monthly temperature and chlorinity at the various stations from 1953 to 1957. Fig. 27 shows the monthly water temperature and chlorinity in 5-year averages.

According to these, the annual changes in chlorinity in the surface and in the 10 m deep strata show respectively 6.61 - 17.62‰ (average of 14.30‰), 14.64 - 18.02‰ (17.04‰) in Shinmaiko. In the Mikawa bay, it is 13.55 - 17.83 (16.44‰) and 17.50 - 17.94‰ (17.64‰); in the Irago waterway, it is 14.90 - 18.56‰ (17.33‰) and 17.68 - 18.65‰ (18.10‰). In Goza, it is 13.41 - 19.21‰ (17.38‰) and 14.44 - 19.20‰ (18.09‰). In the Atsumi outer sea, it is 17.54 - 19.15‰ (18.71‰) and 18.52 - 19.16‰ (18.84‰). Except for the Atsumi outer sea, the low salinity is evident in the surface waters at all stations during May - September. This is more particularly noticeable in Shinmaiko. The May - July period corresponds to the green sea cucumber spawning period in the said areas. The larvae having settled in the shallow places along the coasts have many opportunities to be directly affected by the surface waters. It seems that during this period, the low salinity of the surface waters plays an important role in determining the distribution of the green and of the red sea cucumbers.

If we assume our estimations to be correct, it becomes possible to explain the state of distribution to the green and of the red sea cucumbers, and by knowing the ranges of lowest salinity in the surface waters and of maximum salinity in the bottom strata, one may know the salinity ranges well suited to the green and to the red sea cucumbers.

It is surmised that the 6.6‰ average chlorinity in the surface waters around Shinmaiko, and more particularly in July constitutes a serious obstacle to settled survival. On the basis of the results obtained in the 56
Mikawa bay, the salinity suited to the green sea cucumber is the 13.6 - 17.9‰ (average of 17.0‰) chlorinity. On the basis of the results obtained in the Irago waterway and Goza, the range suited to the red sea cucumber is estimated to be 13.4 - 19.2‰ (17.7‰). The red sea cucumber adapts to higher salinity. The upper limiting value is particularly high. The lower limit value of the salinity range suited to the green and the red sea cucumber will be examined further in the following chapter on the basis of the results of resistance tests. 57

We will also deal in the following chapters with the water temperature.

E - Ecology of the young sea cucumbers

Mitsukuri (1903) gathered from mid to late July in Misaki, Kanagawa Prefecture young sea cucumbers with body lengths of 3.5 - 12.5 mm. Imai et al (1950) succeeded in feeding manamako artificially, and explained the metamorphoses and growth of the young sea cucumbers.

No chromatophores develop yet in mid-August along the coasts of 59
the areas concerned. One finds young sea cucumbers transparent in color with a body length of about 5 mm. However, at the time of the large night tides of November - December, it is easy to find larger sea cucumbers fry.

Graph 28 shows the correlation between the body length and the total weight of young sea cucumbers. From the 14 - 21 mm body length and 0.05 - 0.20 g total body weight, the development of chromatophores becomes noticeable, and there occurs a clear separation between the green and the red sea cucumbers.

As Mitsukuri (1903) already explained, the young sea cucumbers become attached to the underside of tidal zone stones, to the weeds fixed on reefs or to the stalks of ajimo*. From the time of the larval period, they strongly turn away from the light and hide during the day which makes them hard to find. We were completely unable to find any in other places.

Would it therefore be impossible for the larvae to settle in deep places or sandy mud sediment zones? If this were impossible, to what conditions could it be due? This is an extremely important matter with regard to the ecology of young sea cucumbers. In order to first examine whether the larvae can settle and survive in deep places, we built collectors** such as shown in Fig. 29, placed them at the 6 sites of 60
different depths shown in Fig. 16 (depth: a. 2.5 m, b. 5.0 m, c. 10 m,

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*translator's note: meaning not quite certain; probably "eel grass"; same on pp. 68, 118 of this translation.

**We tied together 3 - 4 equal-size twigs of defoliated chinquapin about 60 - 70 cm in length into one bundle. We attached 15 - 16 bundles in alternation to a thick hemp palm rope, added weights and dropped to the sea bottom.

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d. 11 m, e. 14 m, f. 15 m) and during the 3 months of June, July, August twice a month, lifted the faggots made of 2 - 3 bundles and examined the state of young sea cucumber settling.

The surface of the faggot branches cast in the sea became soon covered with a film-forming matter like agar. Many 2 - 4 mm juvenile starfish or spider starfish had become attached, but we saw no young sea cucumbers having become attached during the above period.

There is much doubt as to whether the collectors used were providing the conditions required for larval sea cucumbers to become settled. It is extremely rare to find settled young sea cucumbers on the cluster branches used to capture eels which are placed in the seaweed fields from summer till fall. According to the words of the people experienced in using small sailing trawls in shallow waters, small individuals are never seen in deep offshore waters even when large numbers of young sea cucumbers with a body length of 1 - 3 cm are caught from December to February-March in the seaweed fields in the years when young sea cucumbers are abundant.

The above facts and the water depth based sea cucumber size stratification explained in the former chapter suggest that to become settled and to survive, the larval sea cucumbers need absolutely rocky reefs, seaweed field zones and the like which provide attachment bases, and that they similarly require the presence of attached algae and the like

which are used as food. We will explain in chapter 10 the feeding characteristics of the young sea cucumbers.

Chapter 5 - Resistance to low salinity

Materials and methods

From January to May 1959 we prepared test waters of various salt concentrations by diluting seawater with freshwater inside concrete water tanks 106 x 76 cm (volume of water of about 200 L) and 181 x 181 cm (volume of water: about 1,000 L) in dimensions. We put in the same tanks 10 - 15 green and 10 - 15 red sea cucumbers with a body wall weight of 15 - 75 g, and examined their resistance to law salinity waters. The material used in the tests had been collected in Ehima, Ikawazu and Irago. We used the material for test 3 - 5 hours after capture.

To know whether the sea cucumbers were alive or dead, we picked them up and examined the occurrence or absence of a shrinking reaction when prodded mechanically. When not clear, we returned the individuals for 2 - 6 hours to normal seawater and performed a second examination. Those individuals showing no shrinking reaction at the time their body was being pierced showed no sign of reviving either after being returned later to ordinary seawater.

The salinity of the various tanks was adjusted every 3 days by replenishing the volume of water lost by evaporation. We performed no water temperature regulation.

Results

Table 11 shows the results for the water temperature range of 2.4 - 7.6°C (average water temperature: 4.9°C), Table 12 the results for 4.9 - 13.9°C (11.2°C) and Table 13 the results for 15.6 - 21.7°C (18.7°C).

The sea cucumbers placed in the low-salinity water, pulled in their wartlike processes and tube feet, and contracted their body into a potato shape. They died without almost any motion during the testing period. When the chlorinity is 8% or lower, the above condition is generally observed.

In seawater with a chlorinity of 5.1% or lower, both the green and the red sea cucumbers tend to die in a quite similar fashion, irrespective of the water temperature. Half of the deaths occurred within 8 - 17 hours. All individuals died within 9 - 24 hours.

In seawater with a chlorinity of 5.8 - 9.9%, a fair number of both green and red sea cucumbers died within a short period of time. The 62
resistance is particularly lower in the case of the red sea cucumbers. For both the green and the red sea cucumbers, the harm inflicted tended to worsen in waters of a higher temperature.

In seawater with a chlorinity of 11.4‰, the green sea cucumbers showed at least 10 - 12 days after the start of the tests a normal crawling posture and they seemed to adapted. During the two following months they were quite healthy and began to feed. Yet, from the start the red sea cucumbers did not use their tube feet at all.

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After 8 - 10 days the epidermis on the back of the body began to shrivel and some individuals died. Half were dead after 14 days, and all were dead after 22 days.

In the 12.6‰ chlorinity seawater, the green sea cucumbers were extremely healthy, but 50% of the red sea cucumbers were dead after 30 days.

When green or red sea cucumbers are left for a long time in low-salinity seawater, the epidermis of the back of the body turns white and shrivels. In 11.4‰ chlorinity seawater, 50% of the green sea cucumbers were shriveled after 16 - 20 days. With a chlorinity of 12.6‰ there is no shriveling. However, all red sea cucumbers shriveled during the same period in 12.6‰ chlorinity seawater. In seawater with a chlorinity of 14.1‰ they were for the first time observed to be quite normal.

Thus, red sea cucumbers are adjusted to a higher salinity than green sea cucumbers. The above results show that the lower limiting value of appropriate salinity is about 12.6‰ for the green sea cucumbers and 14.1‰ for the red sea cucumbers.

Table 4 - Measurement errors of the body length, the body capacity and the total body weight in the green sea cucumber.

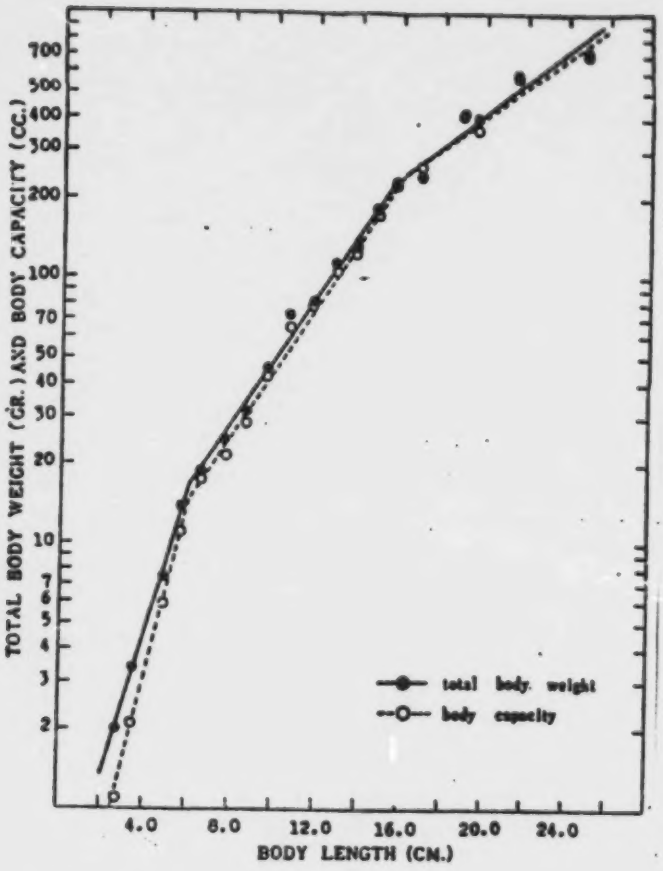
1) 標本	2) 体壁重(g)	3) 体腔水量(cc)	体長 Body lengths (cm) 範囲 Range	平均 Mean	標準4) 偏差 S.d.	変異5) 係数 C.v.	6) 測定誤差	容積 Body capacity (cc) 範囲 Range	平均 Mean	標準4) 偏差 S.d.	変異5) 係数 C.v.	6) 測定誤差	全体重 Total body weight (g) 範囲 Range	平均 Mean	標準4) 偏差 S.d.	変異5) 係数 C.v.	6) 測定誤差
						%	%				%	%					%
1	17	7	7.5— 9.5	8.4	0.85	10.1	7.5	26— 28	27.0	0.82	3.0	1.9	28— 30	29.5	1.00	3.4	2.5
2	25	5	8.0— 8.7	8.3	0.24	2.9	1.7	35— 38	36.4	1.14	3.1	2.4	36— 40	38.2	1.34	3.5	2.7
3	30	12	9.0—12.0	11.1	1.47	13.2	9.5	47— 53	49.5	2.45	5.0	3.5	48— 51	50.3	1.50	3.0	2.2
4	47	25	8.5—10.3	9.3	0.76	8.2	5.7	78— 85	80.8	2.99	3.7	2.1	85— 94	87.3	4.44	5.1	4.1
5	57	15	9.0—10.5	10.1	0.73	7.1	5.2	82— 86	84.8	1.89	2.2	1.6	88— 99	93.0	3.36	3.6	2.7
6	61	32	14.0—16.0	15.0	1.00	6.7	5.3	115—119	117.0	1.58	1.4	1.0	121—126	123.4	2.07	1.7	1.4
7	64	82	13.3—16.7	14.3	1.46	10.2	7.8	172—184	176.6	4.58	2.6	2.5	182—193	186.8	4.51	2.4	2.0
8	68	33	12.3—16.3	14.1	2.09	14.8	8.4	122—132	127.8	4.35	3.4	2.5	135—138	136.5	1.29	1.0	0.7
9	91	—	16.0—17.3	16.7	0.57	3.4	2.7	164—175	168.3	4.79	2.9	3.2	178—186	181.3	3.59	1.0	1.5
10	113	65	18.5—19.8	18.1	1.25	6.9	5.4	233—241	237.3	3.83	1.4	1.4	243—250	246.8	3.30	1.3	1.1
11	127	59	15.3—17.0	15.9	0.69	4.3	3.3	217—244	228.2	11.47	5.0	7.6	235—250	245.6	6.11	2.5	4.8
12	145	132	17.0—18.5	18.1	0.72	4.0	2.9	317—407	361.0	40.46	11.2	9.2	329—415	376.5	39.78	10.6	8.6
13	154	79	16.0—19.0	17.1	1.32	7.7	5.4	269—275	271.5	2.65	1.0	2.5	277—286	282.0	4.24	1.5	1.2
14	183	115	21.3—22.3	22.0	0.21	9.6	0.6	365—374	369.3	3.77	1.0	0.7	377—392	383.8	6.24	1.6	1.1
15	203	173	21.0—23.0	22.0	0.82	3.7	2.3	460—488	474.5	12.15	2.6	2.0	490—499	493.3	3.95	0.8	0.7
16	221	172	21.0—23.0	21.3	0.88	4.1	3.2	458—500	471.2	16.83	3.6	2.4	476—492	484.8	6.72	1.4	1.1
平均 Mean						7.3	4.8				3.3	2.9				2.8	2.4

1) Specimen
2) Weight of body wall
3) Coeliac water
4) Standard deviation
5) Coefficient of variation
6) Measuring error

Table 5 - Measurement errors of the body length and the total body weight in the red sea cucumber. 34

1) 標本	2) 体壁重 (g)	3) 体腔水量 (cc)	体長 Body length (cm) 範囲 Range	平均 Mean	4) 標準偏差 S.d.	5) 変異係数 C.v.	6) 測定誤差 %	全体重 Total body weight (g) 範囲 Range	平均 Mean	4) 標準偏差 S.d.	5) 変異係数 C.v.	6) 測定誤差 %
1	16	7	6.8— 7.5	7.2	0.57	7.9	3.1	28— 30	29.2	2.19	7.5	3.3
2	35	10	9.2— 9.8	9.5	0.51	5.4	2.4	60— 63	61.4	2.28	3.7	1.4
3	36	5	7.0— 7.5	7.3	0.36	4.9	1.4	51— 55	52.8	3.29	6.2	2.6
4	61	3	10.2—11.5	10.9	1.05	9.6	3.9	96— 98	96.4	1.79	1.9	0.7
5	68	23	9.7—12.0	10.5	1.97	18.8	7.4	107—112	109.8	3.58	3.3	1.0
6	74	27	11.0—12.5	11.5	1.24	10.8	3.8	130—133	132.0	2.45	1.9	0.7
7	74	14	10.7—13.2	11.7	1.97	16.8	6.3	108—115	112.0	5.48	4.9	2.0
8	84	14	11.0—12.5	11.7	1.14	9.7	3.6	139—144	141.8	5.18	3.7	1.6
9	115	41	15.5—17.2	16.2	1.25	7.7	2.5	196—204	199.4	5.93	3.0	1.0
10	115	46	17.0—18.2	17.7	0.92	5.2	2.0	194—203	197.8	7.89	4.0	1.5
11	118	24	15.1—18.0	17.0	2.31	13.6	4.8	198—210	203.6	8.67	4.3	1.4
12	150	62	12.8—13.8	13.3	0.80	6.0	2.4	277—290	282.0	9.90	3.5	1.3
13	155	19	15.0—20.5	18.2	4.65	25.6	10.5	216—236	221.4	16.52	7.5	2.6
14	162	61	13.5—20.3	16.3	7.12	43.7	19.1	224—270	258.6	38.96	15.1	5.4
15	208	105	19.8—23.7	21.6	2.96	13.7	5.2	376—402	387.6	21.19	5.5	2.2
16	244	69	24.4—27.0	25.3	2.28	9.0	3.7	413—454	428.2	31.02	7.2	2.5
平均 Mean						13.0	5.1				5.2	2.0

1) Specimen
2) Weight of body wall
3) Coeliac water
4) Standard deviation.
5) Coefficient of variation.
6) Measuring error



35

Fig. 10 - Relations of the body length to the total body weight and to the body capacity in the green sea cucumber.

Table 6 - Values of constants in equations of the body length over the total body weight and the body capacity in the green sea cucumber. 36

体　長 Body length (cm)	log TW = log a + (b·log e)L		log V = log a + (b·log e)L	
	log a	b log e	log a	b log e
<6.0	−0.4434	0.2729	−0.8794	0.3369
6.0—16.0	0.5051	0.1189	0.4323	0.1285
>16.1	1.4453	0.0591	1.5301	0.0542

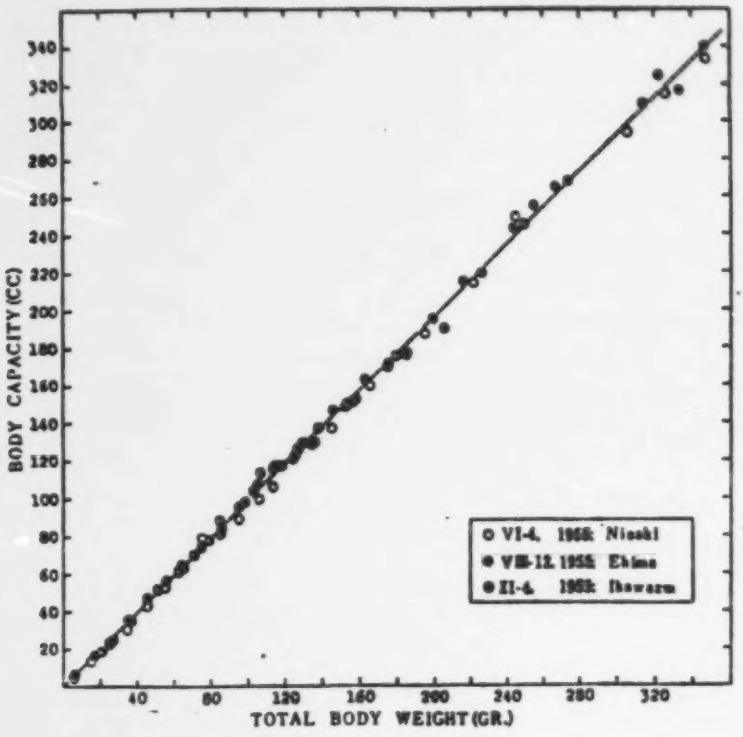


Fig. 11 - Relation between the total weight and the body capacity in the green sea cucumber. 37

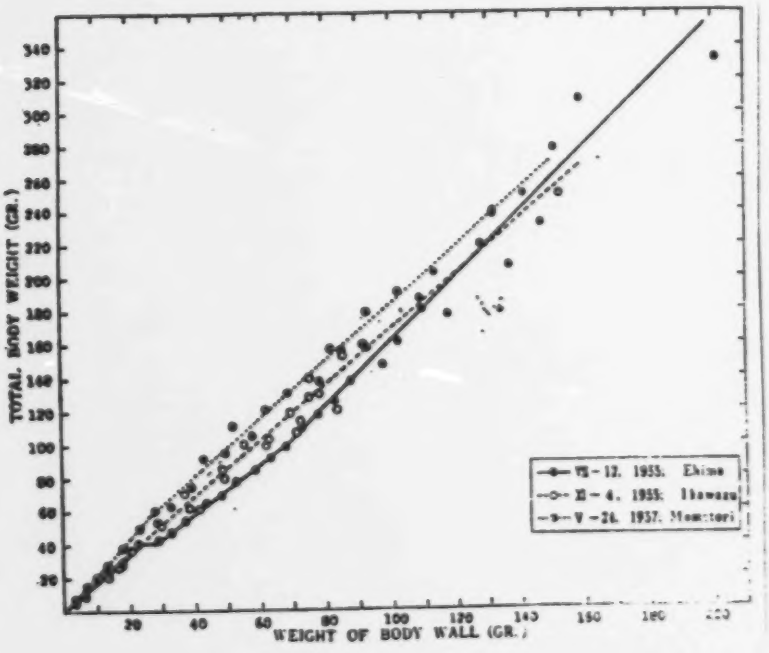


Fig. 12 - Relations between the weight of body wall and the total body weight in the green sea cucumber. 38

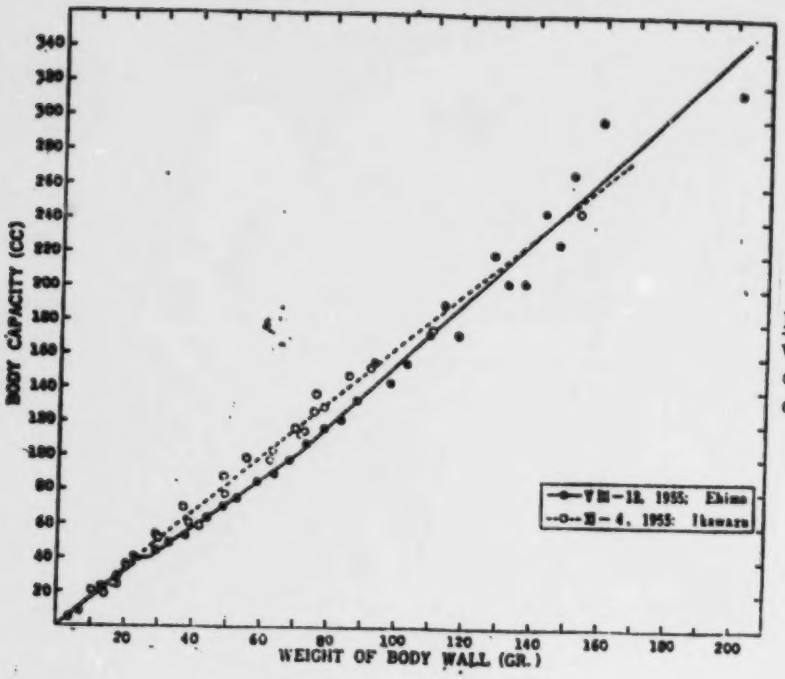


Fig. 13 p Relations between the weight of body wall and the body capacity in the green sea cucumber. 39

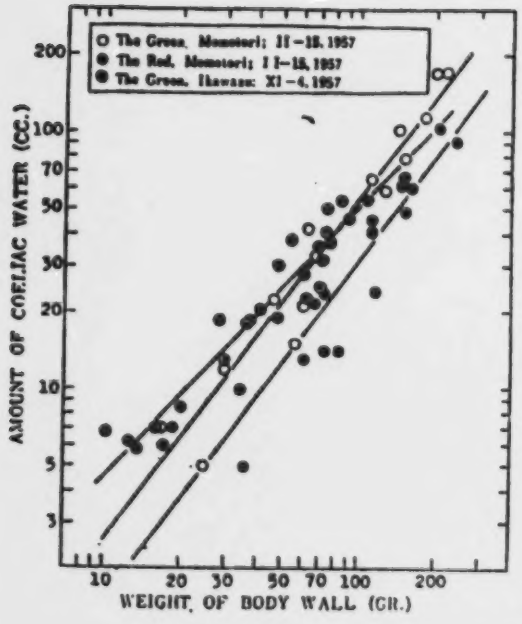


Fig. 14 - Relations between the weight of body wall and the amount of coeliac water. 40

Table 7 - Values of constants in equations of the weight of body wall over the total body weight and the body capacity in the green and the red sea cucumber. 40

月日 Date	産地 Locality	湿重 Weight of body wall (g)	TW=b·MW, TW=a+b·MW a	b	V=b·MW, V=a+b·MW a	b
1955, VIII—12	江比間 Ehima	<25	-	1.723	-	1.670
		25—70	−1.034	1.723	2.469	1.403
		>71	−33.237	1.945	−27.079	1.831
1955, XI—4	伊川津 Ikawazu	<25	-	1.728	-	1.637
		>25	1.185	1.666	2.945	1.619
1957, V—24	鍬取 Momotori	<25	-	2.187 (2.024)	-	-
		>25	12.045 (15.296)*	1.714 (1.674)	-	-

* アカナマコ The Red

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Fig. 15 - map of Atsumi region Aichi Pref.) showing the location of the 28 sampling station. Crosses (a-f) show the location where the collectors of the young cucumber were set. 42

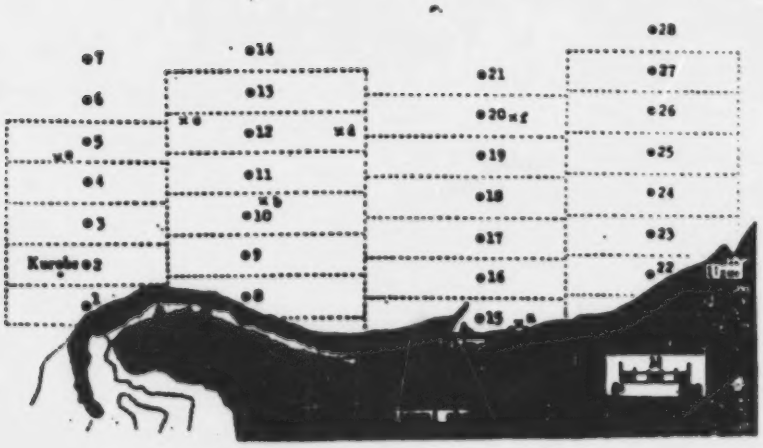

Table 8 - Physical and chemical characteristics of bottom water and the bottom sediment at each station, May 5, 1956.

調査地点 St. No.	時刻 Time	水深 Depth (m)	水温 W.t. (°C)	塩素量 Cl (‰)	酸素量 O_2 (cc/L)	酸素飽和度 O_2—Sat. (%)	有機炭素* Org.—C (mg)	有機窒素* Org.—N (mg)	C/N
1	8.42	205	16.2	17.14	5.43	92.6	369.7	48.48	7.63
2	9.02	370	15.7	17.36	5.17	87.6	511.3	64.93	7.83
3	9.13	460	15.6	17.39	4.55	77.0	1,118.2	86.02	13.00
4	9.22	615	15.2	17.50	5.24	88.1	689.9	56.84	12.14
5	9.30	1,650	15.3	17.11	5.81	88.1	707.6	70.04	10.10
6	9.43	1,790	15.2	18.29	5.39	91.5	1,696.0	139.54	12.15
7	9.51	1,840	15.1	18.32	5.20	88.3	2,462.3	201.10	12.25
8	10.04	175	17.2	16.44	5.72	98.3	493.3	64.64	7.63
9	10.15	315	16.1	16.77	6.15	104.2	603.0	44.44	13.57
10	10.23	420	15.9	17.26	5.75	97.7	237.4	32.19	7.37
11	10.31	563	15.5	17.42	5.95	100.5	1,051.6	89.94	11.69
12	10.41	885	15.4	17.20	5.39	90.7	1,308.3	127.84	10.23
13	10.52	1,765	15.2	18.03	5.36	90.7	2,197.2	178.58	12.30
14	11.05	1,705	15.2	18.10	5.39	91.2	2,364.6	196.51	12.03
15	11.36	315	16.5	16.95	6.69	114.5	470.5	44.35	10.61
16	11.45	460	16.0	17.35	5.83	99.3	455.6	44.35	10.27
17	11.54	500	15.7	17.46	5.77	97.9	1,276.2	107.12	11.91
18	12.02	625	15.4	17.47	5.74	96.9	1,798.7	189.00	9.52
19	12.10	1,385	15.2	18.04	5.92	100.2	597.7	45.50	13.14
20	12.20	1,565	15.2	18.06	5.89	99.8	2,265.9	205.90	11.00
21	12.32	1,580	15.2	18.07	5.85	99.0	2,549.6	207.96	12.26
22	13.13	465	15.4	17.53	6.59	111.3	593.9	52.78	11.35
23	13.23	590	15.4	17.51	6.23	105.2	467.1	40.44	11.55
24	13.30	1,105	15.1	17.90	6.03	101.8	408.4	32.22	12.68
25	13.38	1,135	15.2	17.95	6.04	102.2	332.9	52.26	6.37
26	13.47	1,270	15.3	17.98	5.83	98.8	589.2	41.20	11.30
27	13.56	1,490	15.2	17.98	5.74	97.1	930.2	85.75	10.85
28	14.10	1,590	15.2	17.94	5.79	97.9	1,592.8	145.18	10.97

* 風乾底土 100 g 中の含量

Mg. in 100 gr. of dried bottom sediments.

Fig. 16 - Distribution of depth (m). 43

Fig. 17 - Distribution of bottom water temperature (C°). 45

Fig. 18 - Distribution of chlorinity (‰) of the bottom water. 46

Fig. 19 - Distribution of dissolved oxygen content of the bottom water (cc/L). 46

Fig. 20 - Distribution of oxygen saturity of the bottom water (%). 47

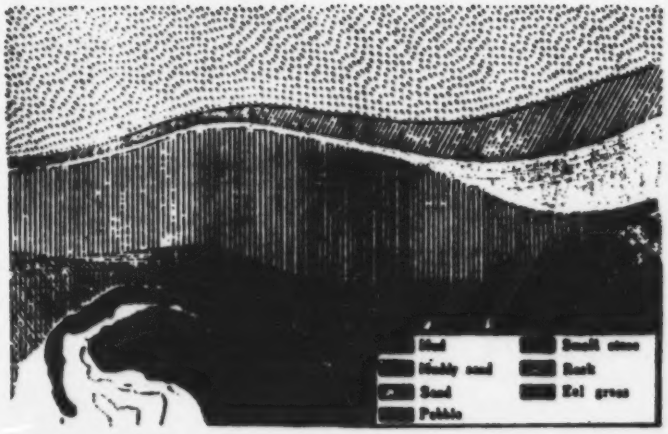

Fig. 21 - Sketch map showing the character of bottom types. 47

Table 9 - Mechanical analysis of bottom sediments.

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調査地点番号 St. No.	底質性状 Property	分析試料量 Sample weight (g)	粒子の分類（直径mm）と組成（%） Classification of particles (diam. in mm.) and composition (%)					
			礫 Pebble >3.00	大砂 Very coarse sand 3.00—1.00	中砂 Coarse sand 1.00—0.50	小砂 Medium sand 0.50—0.20	細砂 Fine sand 0.20—0.05	泥 Mud <0.05
1	GS	11.35	45.24	13.80	5.40	8.10	26.25	1.20
2	PS	11.15	85.93	1.70	1.96	2.32	7.09	1.00
3	GS	13.14	60.86	7.72	6.04	9.24	13.78	2.36
4	GS	8.77	50.80	13.57	9.86	14.15	9.49	2.13
5	sM	6.11	0.00	0.00	1.26	24.78	55.42	18.54
6	Mf	5.14	0.00	0.00	0.00	0.00	49.50	50.10
7	Mf	5.35	0.00	0.00	0.00	0.00	36.65	65.35
8	GS	13.44	83.10	8.37	3.36	1.54	3.19	0.45
9	PS	14.24	60.15	6.97	6.64	12.44	12.70	1.10
10	GS	19.20	61.10	6.53	7.17	16.77	6.86	1.57
11	GS	16.53	59.47	12.34	7.54	11.69	6.38	2.57
12	GS	17.34	69.37	17.46	9.56	1.19	1.18	1.29
13	Mf	5.10	0.00	0.00	0.00	0.00	46.93	53.07
14	Mf	5.49	0.00	0.00	0.00	0.00	41.49	58.51
15	P	25.12	74.22	1.68	1.34	5.17	15.76	1.84
16	GPS	21.42	45.42	12.27	7.53	10.19	23.01	1.58
17	GS	14.31	61.48	9.96	7.16	6.39	10.47	4.54
18	GS	13.10	73.52	13.92	1.29	1.70	2.31	7.26
19	sM	10.99	0.00	1.54	3.21	30.19	55.10	9.96
20	Mf	4.02	0.00	0.00	0.00	0.00	45.45	54.55
21	Mf	4.88	0.00	0.00	0.00	0.00	46.01	53.99
22	S	14.55	30.73	21.09	14.97	8.82	22.42	1.97
23	GS	19.83	49.51	13.77	8.46	6.74	19.62	1.90
24	S	12.78	0.00	1.40	1.56	27.63	65.74	3.68
25	S	13.05	0.00	0.38	0.40	46.56	48.13	4.52
26	sM	10.90	0.00	0.00	0.53	22.84	67.22	9.41
27	Mf	8.49	0.00	0.00	0.00	3.81	66.05	25.14
28	Mf	7.07	0.00	0.00	0.00	5.11	46.58	48.31

P : Pebbles, G : Gravels, S : Sand, sM : Sandy mud, Mf : Fine mud.

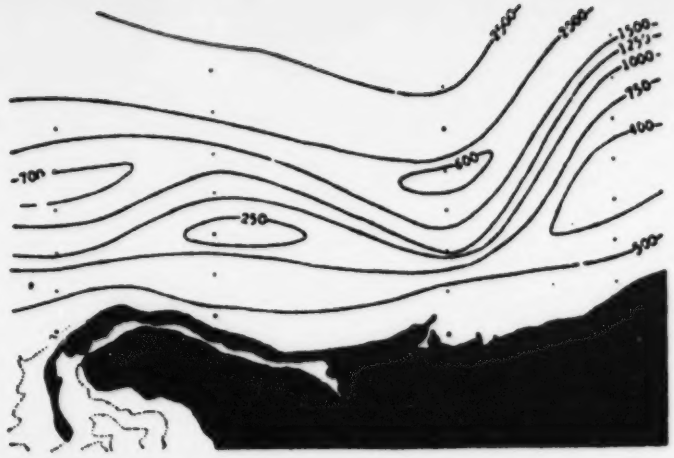

Fig. 22 - Distribution of organic carbon in bottom sediments. 49

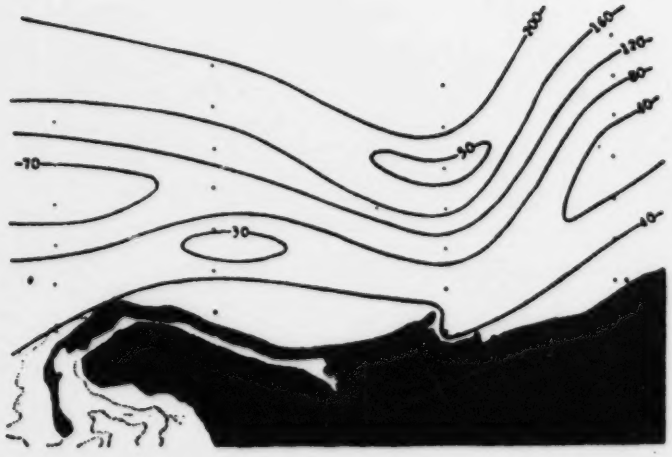

Fig. 23 - Distribution of total organic nitrogen in bottom sediments. 49

Table 10 - Numbers and biomass of the green sea cucumber estimated 51
on the basis of quantitative sampling records at each station.

調査地点番号 Station No.	漁獲尼数 Catch in number*	平均全体重 Mean body weight (g)	100㎡の漁獲尼数 Catch numbers per 100 sq. m.	面積 Area (x100 sq.m.)	総尼数 Total number	総現存量 Total biomass (kg)
1	9	54.7	3.00	2,075	6,225	340.0
2	14	65.7	4.67	3,525	16,462	1,081.6
3	8	91.3	2.67	3,525	9,412	859.3
4	3	153.2	1.00	3,525	3,525	540.0
5	1	208.3	0.33	3,525	1,163	242.3
6	0	-	-	-	-	-
8	12	58.5	4.00	2,950	11,800	690.3
9	13	47.2	4.03	4,388	17,682	834.6
10	11	73.2	3.67	4,388	16,102	1,178.7
11	10	116.8	3.03	4,388	13,294	1,552.7
12	9	142.1	3.00	4,388	13,163	1,870.5
13	1	202.6	0.33	4,388	1,448	293.4
14	0	-	-	-	-	-
15	29	51.2	9.67	1,806	17,467	894.3
16	17	62.1	5.67	4,500	25,515	1,584.5
17	14	83.9	4.67	4,500	21,015	1,763.2
18	11	145.9	3.67	4,500	16,515	2,409.5
19	7	189.8	2.03	4,500	9,135	1,733.8
20	2	216.5	0.67	4,500	3,105	652.7
21	0	-	-	-	-	-
22	21	58.4	7.00	2,275	15,925	930.0
23	24	87.7	8.00	3,750	30,000	2,631.0
24	15	135.2	5.00	3,750	18,750	2,535.0
25	18	153.2	6.00	3,750	22,500	3,447.0
26	11	173.0	3.67	3,750	13,763	2,381.0
27	6	197.2	2.00	3,750	7,500	1,479.0
28	7	221.7	2.03	3,750	3,863	856.4
計 Total				90,146	315,239	32,781.3

* 網口の長さ3mのナマコ用桁網を100m曳網する。
Catch in number of 300 sq. m.

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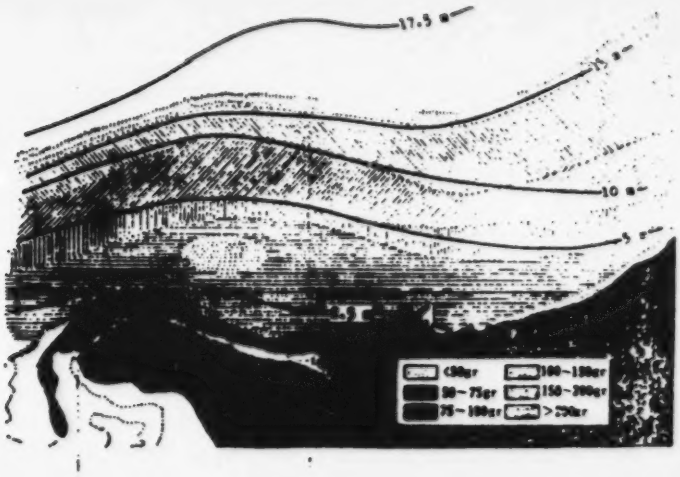

Fig. 24 - Size (total body weight) distribution of the green sea cucumber in relation to the depth.

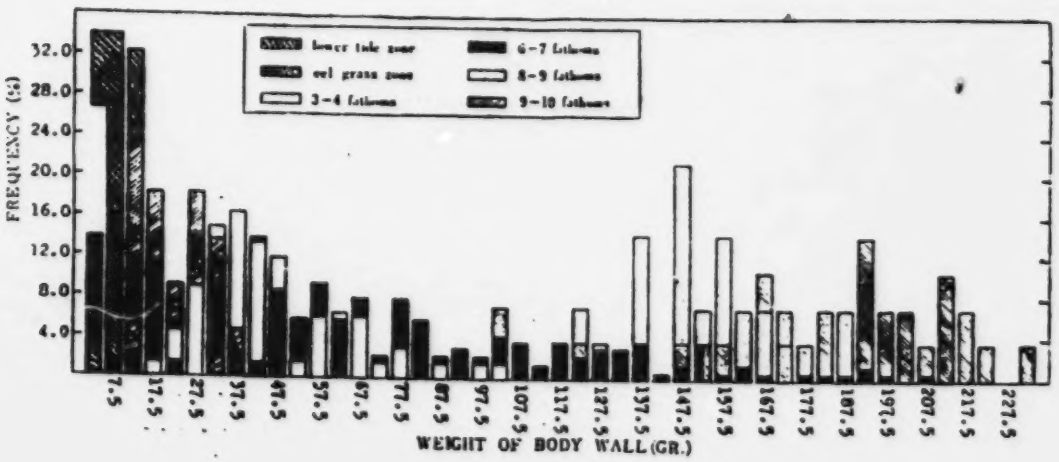

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Fig. 25 - Relation between size distribution of the green sea cucumber and its relative abundance from different depth.

56

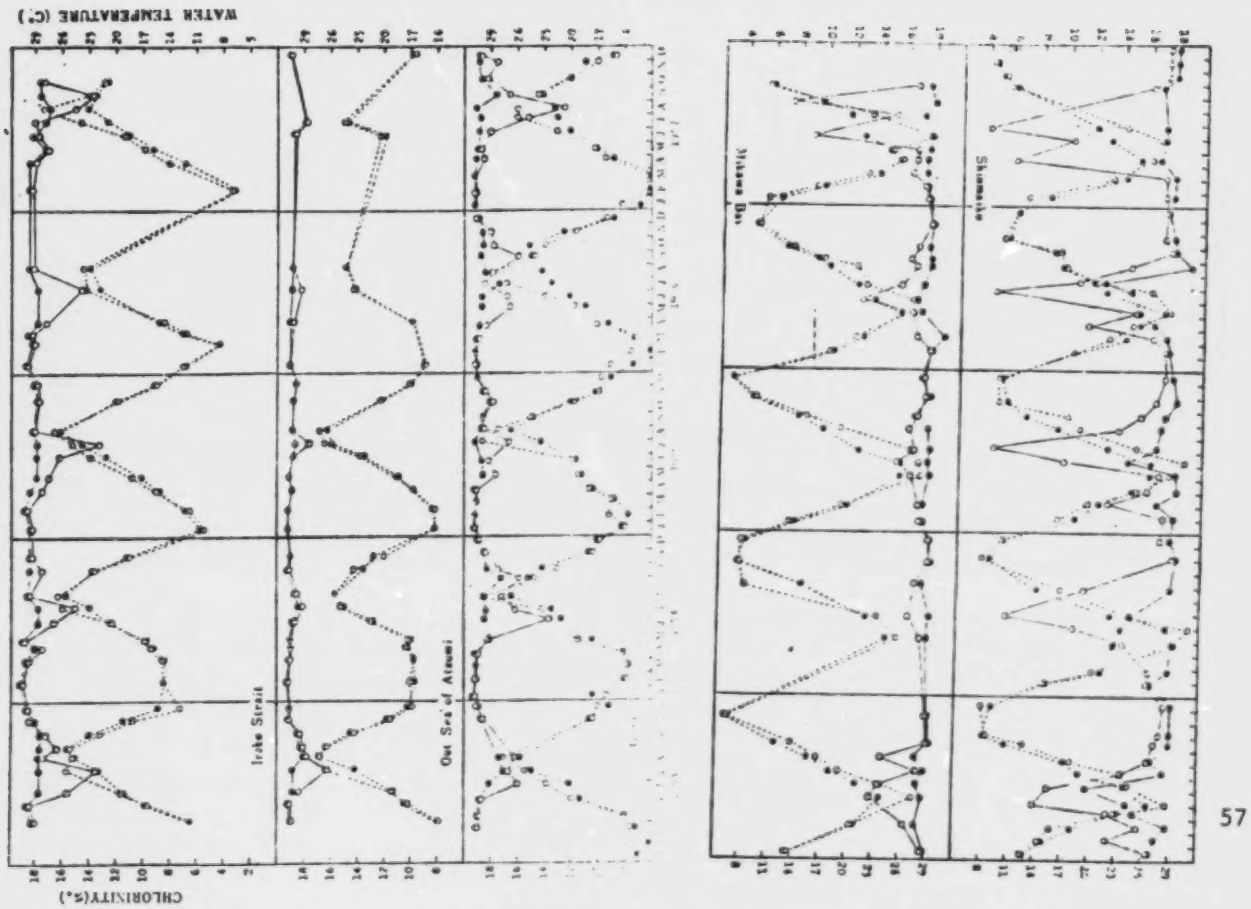

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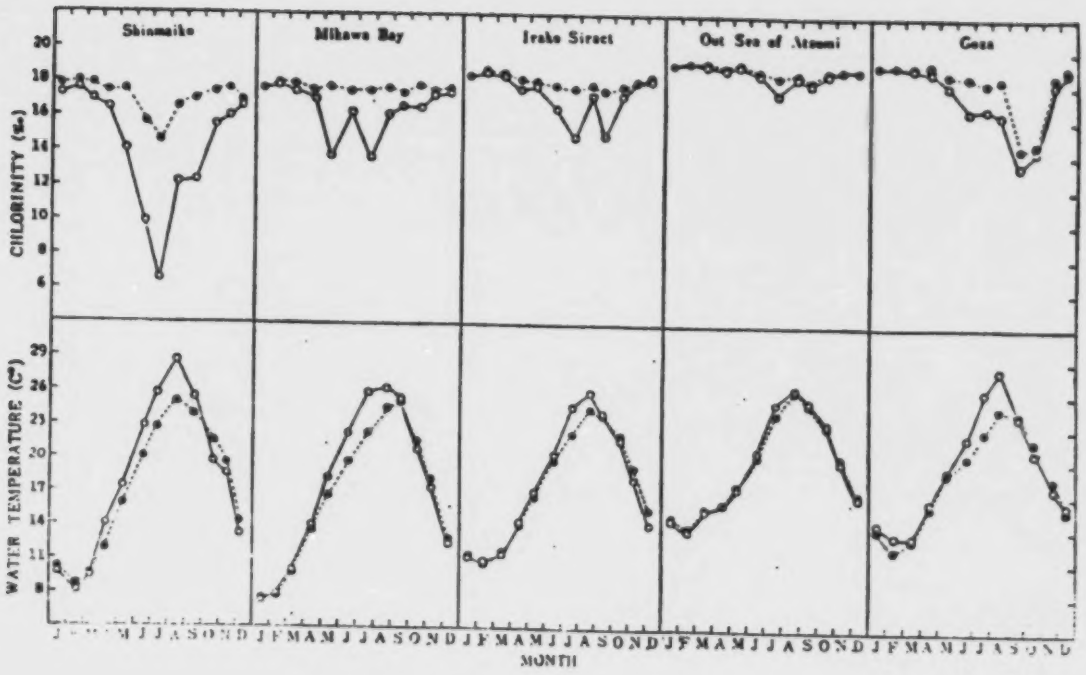
Fig. 26 - Comparisons of the monthly mean chlorinity (solid line) and the water temperature (dashed line) from 1953 to to 1957. Circles (o) represent the 0 meter and solid circles (•) are the 10 meters layer.



58

Fig. 27 - Comparisons of the monthly mean chlorinity and the water temperature. Circles (o) represent the 0 meter layer and solid circles (•) the 10 meters layer.

Table 11 - Resistance of the green and the red sea cucumber to low chlorinity at the water temperature of 2.4 - 7.6°C.

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塩分 Chlorinity (‰)	50% 致死(時間) 50% mortality (hrs)		100% 致死(時間) 100% mortality (hrs)	
	アオナマコ The Green	アカナマコ The Red	アオナマコ The Green	アカナマコ The Red
2.60	10.5	9.0	15.0	15.0
5.07	12.0	9.0	24.0	24.0
7.26	72.0	26.8	96.0	50.0
9.43	11.5 days	6.4 days	16.0 days	9.0 days
11.44	—	14.0 days	—	22.0 days
12.58	—	30.0 days		

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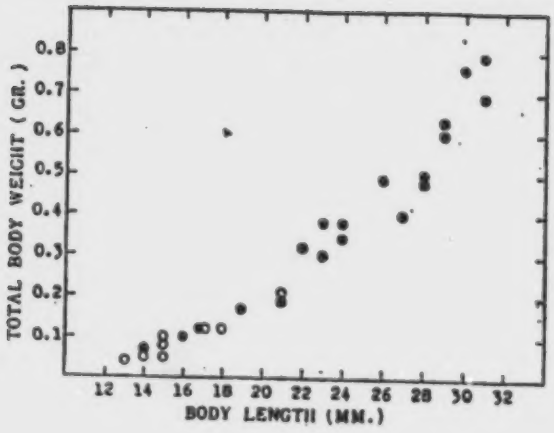

Fig. 28 - Relation between the body length and the total body weight of young sea cucumbers.
o: The characteristic color pattern of the green and the red are not distinguishable.
•: The characteristic color pattern of the green and the red are distinguishable.

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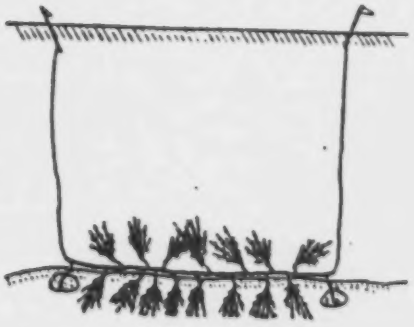

Fig. 29 - The apparatus for collecting of young sea cucumbers.

Table 12 - Resistance of the green sea cucumber to low chlorinity at the water temperature of 4.9 - 13.9C°. 62

塩分 Chlorinity (‰)	50% 致死 50% mortality (hrs)	100% 致死 100% mortality (hrs)
1.94	8.0	16.0
3.82	17.0	24.0
5.76	59.0	78.0
7.71	100.8	261.0
9.51	15.0 days	—
11.38	*	

* 2箇月間斃死なし
Without any mortality for at least 60 days.

Table 13 - Resistance of the green and the red sea cucumbers to low chlorinity at the water temperature of 15.6 - 21.7C°. 63

塩分 Chlorinity (‰)	50% 致死 (時間) 50% mortality (hrs)		100% 致死 (時間) 100% mortality (hrs)	
	アオナマコ The Green	アカナマコ The Red	アオナマコ The Green	アカナマコ The Red
1.73	11.5	12.0	18.0	18.0
3.43	11.5	12.0	18.0	18.0
4.99	17.0	17.0	24.0	24.0
6.72	27.0	30.0	67.0	39.0
8.33	51.0	34.0	67.0	67.0
9.94	19.5 days *	156.0	—	—
11.00	**	***		

* 19.5日で33.5%斃死 33.5% mortality for 19.5 days.
** 19.5日で 6.7%斃死 6.7% mortality for 19.5 days.
*** 19.5日で25.0%斃死 25.5% mortality for 19.5 days.

Chapter 9 - Reproduction

While some sea cucumbers such as Cucumaria planei, Holothuria surinamensis, H (Actinopyga) parvula, H (Act.) difficilis reproduce sexually, some species are known to multiply asexually by division depending on the cases (Crozier, 1907; Deichman 1932; Kille, 1936). Moreover, Leptosynapta inhaerens (Müller)*, Synapta maculata** and other species belonging to the Synaptidae easily cut themselves off due to stimulations from deteriorating environment and such (Pearse, 1909; Domanty, 1931). Thyone briareus and H. atra (kuronamako), H. sanguinolenta, Stichopus chloronotus and such belonging to the Cucumaridae are known to cut themselves off due to stimulation such as that of chemicals (Pearse, 1909; Domanty, 1931; Kille, 1931, '35). It is not known whether self-severance in these species is normally employed as a method of asexual multiplication. However the body segments separated because of severance may evolve into individuals exercising separately organic sexual reproduction. This has been demonstrated by the studies of Torelle (1909) about Thyone briareus and Cucumaria grubi, of Bertolini (1932) about Holothuria tubulosa and of Kille (1942) about H. parvula.

No matter how stimulated, no green or red sea cucumbers can be induced to cut themselves. However, one might consider an asexual

Note: *Hosoikari namako from Woods Hole
**Oikari namako from the Philippines

reproduction effect due to artificial segmentation of the body. The rule however is sexual reproduction through male-female somatic differences.

In the field of embryological studies of sea cucumbers, much has been accomplished by Kowalevsky (1867), Selenka (1876), Ludwig (1891, '98), Martensen (1894, 1913, '21, '31, '37' '38), Edwards (1907), Clark (1898, 1910), Newth (1916), Oshima (1917, '21), Runnström, J. and S. Runnström (1919), Runnström, S. (1927), Inaba (1937), Hörstandius (1939), Colwin (1948), Wooton (1949) and other scholars. Of these, Mortensen (1921, '31, '37, '38) reported on the early formation of californicus and kefersteini 91 as well as variegatus of the Stichopus genus and on the metamorphoses of variegatus. Inaba (1937) studied the artificial insemination of manamako, and Imai et al (1959) studied artificial rearing of the larvae. Mitsukuri (1903) wrote about young sea cucumbers of the manamako species. There are reports by Mitsukuri (1903), Tokuhisa (1915), Kinoshita - Shibutani (1939), Sang - Oshima (1961) and others about their spawning season. Tanaka (1958b) reported about the seasonal changes in the gonads.

There are reports about spawning by sea cucumbers. They concern Cucumaria kirchsbergi (Kowalesky, 1867), C. planei, H. tubulosa (Selenka, 1876), H. floridana (Edwards, 1909), C. normani (Newth, 1916), Psolus phantapus (Runnström, J. and S. Runnström, 1916), C. echinata (Oshima, 1921), Thyone briareus (Oshima, 1921; Colwin, 1948), H. poli (Hörstandius, 1939) and others. However all species of sea cucumber regarding which spawning induction and artificial insemination are easy belong to the Cucumaridae. Spawning by H. tubulosa and H. floridana has been observed

in crawls only. By raising the pH of the rearing water, one obtained H. poli eggs that could be fertilized. Furthermore, it is reported that those Thyone briareus which missed the opportunity of laying eggs during the first night following capture layed no eggs later either even though they were holding large quantities of eggs.

Induced spawning or artificial fertilization of green and of red sea cucumbers is not easy. Yet, Inaba (1937), Imae et al (1950) surmounted the difficulty, they obtained fertilized eggs and elucidated the metamorphoses. Thyone briareus eggs were layed in a state of mid period of first maturation fission (Oshima, 1925), and it is known that fertilization is difficult without natural egg release (Colwin, 1948). It seems that the same difficult stage occurs in the maturation process of green and of red sea cucumbers.

We will explain here the characteristics of the gonads, the seasonal changes in gonad weight, the spawning seasons, the volumes of eggs held with regard to the green and the red sea cucumbers.

A - Characteristics of the reproductive organs

The gonads of the green and of the red sea cucumbers develop immediately behind the calcareous ring of the mouth part.* It is

*Among the 700 - 800 individuals examined, there were two individuals in which the gonad developed on the general cloaca wall of the caudal anus, one being female and the other being male.

recognizable from a slight hollow in the rim of the gonopore, seen through 92
the gonopore located on the median line at the front of the dorsal part.

In the case of advanced individuals, the gonads appear around the later part of October in the form of small protonemata. In the May - June active multiplication period, well developed gonads in the shape of tree branches divided from the base into ten and more tufts fill the entirety of the body cavity.

Generally the gonads of the red sea cucumbers are thinner and fewer than those of the green sea cucumbers.

The gonads of both females and males present a pale yellow color until they reach about 5 g in weight. As the size increases further, the ovary turns orange and the mature ovary acquires a beautiful dark orange color tinged with red ([2.5 YR] - 6/14).* The testes acquire an overall yellow-milky white color ([7.5 YR] - 8/6)* and it becomes easy to separate the males and females by the color of their gonads.

The immature eggs inside the ovary are colorless transparent and have a large germinal vesicle. They are wrapped in a thin egg membrane and disposed in rows without clear forms. The mature eggs having dropped their membrane are spherical or elliptical and their germinal vesicle is unclear.

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*Based on the colorimetric chart of the Munsel Color System

The smallest biological shape for green sea cucumber was such that the weight of the body wall was 39 g. Generally the size is such that the body wall weight is 58 - 60 g.

B - Maturation of the reproductive organs.

Those red sea cucumbers from Ikawazu, Ehima, Uzue areas along the Atsumi peninsula, Aichi Prefecture having body wall of 40 - 60 g or more have also gonads. Fig. 49 and Table 18 show the proportion* (%) of gonad weight vs body wall weight per month of investigation with regard to the individuals with body wall weight of 50 g and over. From late October, one finds traces of gonads. The development is rapid after early March.

The gonad weight coefficient seems to be somewhat greater for the females during the active spawning period of May - June. However, the gonad weight coefficients are not so evidently different according to females and males during the spawning season. We note a rectilinear regression between the gonad weight coefficient (GI %) and the body wall weight (MW gr) in the early spawning season or immediately following the spawning start. In late April is obtained the primary correlation equation of GI = 0.2161 MW - 10.782 and in late May that of GI = 0.2201 MW - 18.819. 93
Thereafter, as spawning progresses, the relationship becomes irregular. By about late May, the individuals with a body wall weight of about 100 g release about 70% of the original gonad matter, those with a body wall weight of about 150 g, release 34% of the same matter and those with a body

*Gonad weight coefficient

wall of about 200 g release 22% of the same. Spawning takes place for a long continuous period of time, and the sea cucumbers living in deep offshore waters tend to lag behind.

Fig. 50 shows the maturity stages of the ovarian eggs of green and of red sea cucumbers in the above areas and in Momotori, Mie 95
Prefecture. In Momotori, the red sea cucumbers begin to spawn from late March and the green sea cucumbers from early to mid April. In the Atsumi area, the green sea cucumbers seem to start spawning from late April to early May. In the Atsumi area, large sea cucumbers in the deep offshore waters develop well up to mid August and possess gonads.

For 213 individuals examined, the female-male ratio was about equal, showing 1 : 1.09.

Tanaka (1958b) examining the gonads of green sea cucumbers from the Funka Bay, Hokkaido divided into 5 periods, that is, rest, recovery, growth, maturation and release. However, with regard to the green and the red sea cucumbers from the Aichi, Mie Prefectures, the growth, maturation and release periods are continuous. In the August - September period of high water temperature, the gonads disappear completely and one sees no state corresponding to the rest period. In the waters near Hokkaido, the water temperature of the summer is relatively low. As this period does not last for a long time, the low water temperature arrives before the gonads shrink and disappear following the release of the reproductive matters, and the following season reproductive growth is believed to start. In those

areas where the water temperature is high in the summer and where this continues for a long time, the gonads disappear completely in the same period. One knows that even if the primordium of the sea cucumber gonads has disappeared, the formation of gonads for the next season is not hindered (Torelle 1909; Bertolini 1932; Kille 1942).

C - Spawning season and water temperature

The spawning season is closely related to the seawater temperatures at the various sites. In Hokkaido, the spawning season of the green sea cucumbers goes from late June to early September, with the most active period extending from early July to mid August. Along the Pacific coast, the water temperature is 13°C at the start of the spawning season. Along the coast of the Sea of Japan it is 16°C. At the end of the spawning season, the water temperature is judged to be always 20°C (Kinoshita, Shibutani 1939).

In the Mangoku gulf, Miyagi Prefecture from late June to early July, in the Onnagawa bay from late July to late August, the water temperature at the start of the natural spawning was judged to be 20°C (Imai et al, 1950).

In the Nanao Bay of the Sea of Japan, spawning started at 13°C in May - June and was completed at about 22°C (Tokuhisa, 1915).

Along the coast of the Kanagawa Prefecture, the spawning season goes from late April to early July (Mitsukuri, 1903). Along the coasts of the Aichi, Mie Prefectures, the red sea cucumbers spawn in March - April and active spawning takes place from the end of March to early April. Green sea cucumbers spawn from mid-April to early August, with the active period going from mid-May to early July (Sang - Oshima, 1961).

In these places, the green sea cucumbers start spawning when the water temperature is 13 - 15°C. The active spawning period ends at 18 - 22°C. The above results allow us to say that during the green sea cucumber spawning season, the water temperature is 13 - 22°C, that the water temperature is 13 - 16°C at the start of the spawning and that it is 18 - 22°C at the end of the spawning. 96

D - Fecundity of the green sea cucumber.

We weighted carefully parts of the green sea cucumber ovaries in mature condition, removed the ovarian eggs and stained with neutral red. Diluting to an appropriate concentration and measuring the volume of eggs contained in a given volume of water, we converted to the numbers of eggs per ovary unit weight.

Before doing this, in order to know the region of the gonad and to know the computation error due to the volume of gonad used for the measurement, we measured carefully 0.50, 1.15, 1.82, 2.83 g of gonad from regions taken randomly from one specimen. We diluted the eggs of these

portions to 1,000 - 2,500 cc and counted the amounts of eggs contained in 15 cc. The results are shown in Fig. 51.

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The results show that both the differences in egg numbers based on different regions of a mature ovary, and the dilution error within the aforementioned range represent ranges which may be disregarded. Fig. 19 shows the number of eggs per 1 g of ovary when measuring carefully about 1 g at a time of sea cucumber ovaries of various sizes and calculating by the same method. The numbers of eggs per 1 g of mature ovary vary from 183,000 to 263,000 with an average of 209,000. There are thus rather large differences. Large green sea cucumbers with an ovary of about 100 g are estimated to release 18,300,000 - 26,300,000 eggs.

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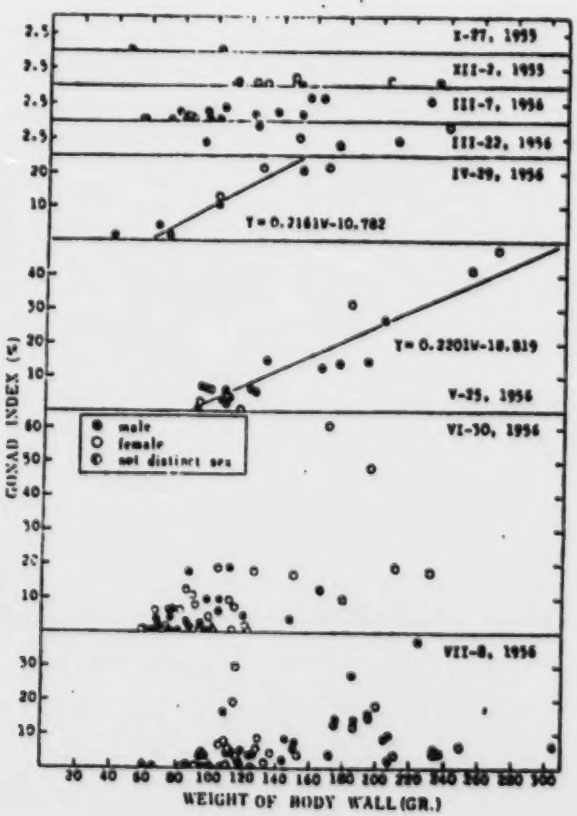

Fig. 49 - Seasonal changes of the gonad index (weight of gonad divided by weight of body wall) in the green sea cucumber. o : Female, • : Male, ● : Sex not clear.

Table 18 - The sex ratio and the gonad index in the green sea cucumber 94

採集年月日 Date	採集個数 No.	生殖巣をもつ個体数 Indiv. no. of maturity	♀ : ♂	生殖巣体数* Gonad index (%)* ♀	♂	採集地 Locality
'55, X—27	89	2 (2.2)	?	0.08 ~ 0.01		江比間沖 Ehima
'55, XII—2	59	9 (15.3)	3 : 3	0.41~0.05	0.20~0.12	江比間沖 Ehima
'56, III—7	62	31 (50.0)	?	0.86 ~ 0.05		江比間沖 Ehima
'56, III—22	4	3 (75.0)	1 : 2	1.47	3.04	江比間沖 Ehima
'56, IV—29	25	8 (32.0)	3 : 5	18.36~2.62	7.52~3.67	江比間湾内 Harbour of Ehim
'56, V—25	20	19 (95.0)	6 : 13	13.25~6.92	11.45~2.87	比江間沖 Ehima
'56. VI—30	95	59 (62.1)	33 : 26	9.82~8.71	4.75~1.13	馬草沖 Magusa
'56, VII—8	94	60 (63.8)	24 : 36	6.12~1.57	6.54~1.34	江比間, 宇和江沖 Ehima, Uzue
'56, VII—12	138	22 (15.9)	13 : 9	—	—	江比間沖 Ehima
計 Total	586	213	86 : 94			

* (Gonad weight/Weight of body wall)×100

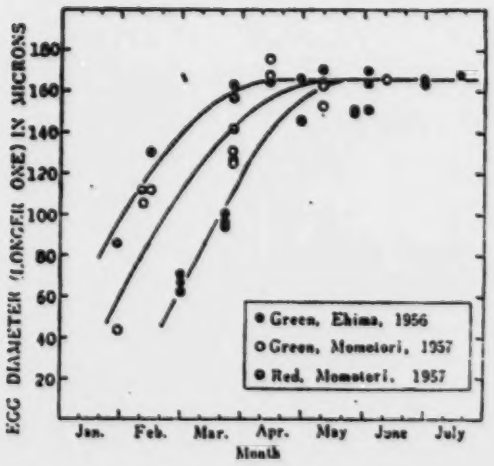

Fig. 50 - The monthly size changes of the ovarian egg (represented by the mean length of longer diameter) in the green and the red sea cucumber.

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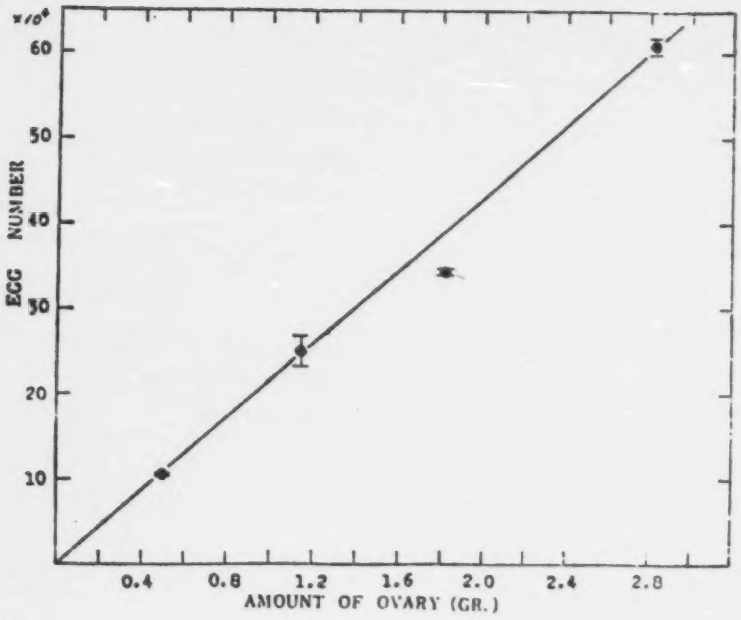

Fig. 51 - Relation between the weight of ovary and number of eggs in the green sea cucumber.

Table 19 - Comparisons of egg numbers per 1 gr. of the matured ovary in the green sea cucumber. 97

体壁 Weight of body wall (gr.)	卵巣量 Ovary weight (gr.)	卵巣1g当りの卵数 Egg number per 1 gr. of ovary
123.0	15.5	207191.1
136.5	23.1	183363.1
163.5	33.0	182254.5
175.0	36.2	262983.0
平均 Mean		208947.9

Chapter 12 - Growth 127

The first to study the growth of the green cucumber was Mitsukuri (1903). On the basis of specimens gathered along the coast in the Kanagawa Prefecture, Mitsukuri studied during 3 years from 1893 to 1895 mainly the growth of sea cucumbers of the year. He reported that after one full year the body length is at most 25 cm and that gonads are present after two years. Later, Tokuhisa (1915) reported regarding the growth of green sea cucumbers from the Nanao Bay in the Ishikawa Prefecture more or less the same growth results as those obtained by Mitsukuri.

The amount of growth indicating a size of up to 24 - 25 cm after a full year reported by the above two researchers represents an excessive value as by our conversions (based on Fig. 10, Table 6) since the total body weight would reach 730 - 830 g. The growth measurement characteristics used by the two researchers are based on body length. 128
However the error regarding the characteristics of body length measurements is great, and we have already explained that the overall reproducibility of the measurement values is quite poor.

Numerous green and red sea cucumbers are produced along the coasts and in the shallow waters. They have been exploited for a long time. Even though they occupied an important position in terms of fisheries product, their growth rate has so far remained unknown. The reason seems to be that errors were most likely with regard to

characteristics such as body length, total weight or capacity used to measure growth due to the ecology and habits of the sea cucumbers, and that on the other hand there was little knowledge of the particular ecology.

So, in order to know the growth of the green sea cucumber, we considered anew the body walls as a measurement characteristic, placed outdoors tanks with currents and placed crawls in natural environments to conduct rearing tests. Considering carefully the ecological characteristics of the green sea cucumbers which have sizes stratified according to habitat depth, we discovered the group growth under natural conditions, basing ourselves on the body wall weight compositions of the specimens collected monthly. On the basis of these results we discussed the growth of the green sea cucumber. Simultaneously, we examined the estimated appropriate release amounts on the basis of the relationship between sea cucumber accommodation density and growth and on the basis of the present results. We obtained the following results.

Material and methods

We performed tests and made observations of the growth of green and red sea cucumbers for 6 years going from 1955 to 1960. We worked at the fisheries experimental station of the Tokyo University in Ikawazu, Atsumi peninsula, Aichi Prefecture. All the materials used were locally produced.

The tests in rearing and developing green sea cucumbers in outside water tanks with a current were conducted from November 1956 to October 1957. We partitioned with boards concrete water tanks with a 186 cm x 186 cm area and a 31 cm water depth as shown in Fig. 64, and divided into the following 6 parts according to feeding and bottom sediment conditions. The unfed part was divided further according to bottom sediment conditions into four sections, that is, one with no bottom sediment, another with sand, another with mud and another with seaweeds (green algae) on sand. The fed part was according to bottom sediment condition further divided into two parts, that is, one with sand and another with rice bran and fish meal (fine powder). Five small sea cucumbers with an average total weight of 20 - 24 g and five 49 - 52 g medium sea cucumbers were placed in each section. The current was kept at 700 - 900 L 1h during the test period.

The green and red sea cucumber growth tests were conducted during the spring - summer period from March to August 1956 (aestivation) and during the fall - winter - spring periods (growth periods) of 1956, 1958, 129 using crawls installed inside the bay. The crawls were made from vinyl-coated wire net with a 0.4 cm mesh and of artificial fiber nets of the same mesh. They had an area of 71 cm x 71 cm and a height of 20 cm. We placed them in a sandy zone 30 cm under the water at the lowest tide line. For the bottom sediment conditions of the crawls, we chose sand and mud. We placed in each crawl 1 - 6 small green sea cucumbers with average total weights of 11.0 - 14.4 g and 3 small red sea cucumbers of 11.7 - 22.3 g, the total of contained sea cucumbers being 1 - 9. We watched their growth inside the crawls.

The tests on accommodation density and growth were conducted in parallel to the tests on growth. We watched the growth condition with regard to the 1 - 48 green sea cucumbers and 3 - 24 red sea cucumbers, the total being 1 - 72 sea cucumbers placed inside crawls of identical areas used for growth tests.

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Results and considerations

A - Rearing and growth of the green sea cucumber in the tank.

The results are shown in Table 33 and Graph 65.

In the group receiving feed, rice bran impregnated with seawater as well as horse mackerel fish meal were dropped every five days so as to be scattered over the entire surface of the bottom sediments. After about 4 weeks, the bottom sediment reduction was very noticeable and feeding by the sea cucumbers had been interrupted completely. So, feeding was discontinued thereafter. In the sand + green algae section, we removed the seaweeds from mid-February and provided the same conditions as for the sand section.

As the results in Table 33 and Fig. 65 show, the sea cucumbers exhibited under their particular bottom sediment conditions respectively different growth results. The correlation with water temperature is particularly remarkable. From late April to the early June borderline water temperature of 16 - 17°C (the daily measurement times were 9.00 -

9.30 but higher temperatures were shown in the middle of the day), there occurred a general decrease in weight which was more particularly remarkable from mid-May to early July.

The small cucumbers achieved the best growth in the sand + green algae section up to around mid-February. This was followed by the growth in the sand section. Up to the maximum growth period of mid-May, the best growth was on the contrary seen in the section without sediment matters. Growth became poorer in the sand + green algae section, sand section, sand + fishmeal section, mud section, sand + rice bran order. The weight increase rates were 3.0, 2.2, 2.2, 1.5, 1.3 and 0.6 respectively. After spending in this situation the high water temperature period of the summer, each of the mud, sand + rice bran, sand + fishmeal section showed weight increase rates of -0.1 - -0.2 so that the sea cucumbers were smaller than at introduction time. In the section without bottom sediments and in the sand section, the weight increase results showed barely 0.5 - 0.8.

Meanwhile the overall growth of the sea cucumbers was poor. The weight increase rate of 0.6 (no bottom sediments) was the maximum reached up to the maximum growth period. By mid-October the weight increase rate was -0.4 - 0.7. All sea cucumbers grew smaller than they were at introduction time. These facts mean that there are differences in the degree of environment requirements depending on the growth stage of the sea cucumbers. Under such restricting conditions, one sees no growth in the large sea cucumbers. Similar facts are noted in the growth tests based on crawls placed in natural environments.

The effect of ingestion interruption* caused by the reduction of the bottom matters upon growth appears from early January to mid-February 134
in the state of growth results regarding the sand + rice bran and sand + fishmeal sections. When recovery from the state of bottom matters reduction occurs, there is renewed feeding.

The good growth results in the section without bottom matters, in the sand + green algae and sand sections represent the instances where there was no feeding impediment caused by the reduction of bottom matters. The good growth results in the section without bottom sediments seen from mid-February are limited to this section after the beginning of the tests and result merely from the fact that diatoms and green algae became gradually attached and that simultaneously the accumulating floating muddy matters were ingested.

Except for the period during which the bottom matters were extremely reduced in the rice bran and fishmeal fed section, the degree of oxygen saturation during the rearing period was in the 89 - 114% range. It was 94 - 114% in the sand + green algae section which seemed to be somewhat higher than in the other sections. Thus, useless to say, there is a relationship between the growth of sea cucumbers and the water temperature. The bottom sediments and water quality conditions are related to feeding and are therefore believed to greatly affect growth.

*One knows the state of ingestion by the volume of excretion in every section of the tank.

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B - Growth in the store boxes

Figs. 66, 67 and Tables 34, 35 show the results of growth tests* performed with green and red sea cucumbers kept inside crawls placed in the low-tide zone of the Ikawazu bay during the spring - summer aestivation period (Tests I) and the fall - spring growth period (Tests II, III). Fig. 68 shows one example of diurnal changes in environmental factors such as salinity, water temperature, current velocity at high tide time in June, July for the sites where the crawls had been placed.

With the growth examples of the tests I, the bottom matters were sand and mud for 6 green sea cucumbers and 3 red sea cucumbers respectively. The growth of the red sea cucumbers was inferior to that of the green sea cucumbers, and the growth of both seemed to be somewhat better under mud sediment conditions. Under natural conditions too the body weight was seen to decrease from late April with a water temperature of 17 - 18°C. By late August, the weight increase rates were about -0.4 - -0.7 for both the green and the red sea cucumbers.

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The growth tests conducted in the fall - spring period followed the growth tests (tests I) conducted from the spring. In some of the tests (tests II) we kept the bottom sediments as they were and used only new sea cucumber specimens. In other tests (tests III, Tables 34, 35) we placed new crawls in sandy and in sand-and-mud zones inside the same bay.

*The detailed values for the in-crawl growth tests I and II are given in Tables 36, 37.

In test II we transplanted 3 green and 3 red sea cucumbers and noted some decrease in weight during the high water temperature period going from late August to mid-September. Thereafter, there was renewed growth as the water temperature decreased. By late May of the following year, the green sea cucumbers on sandy bottom sediments showed a weight increase of 5.4 while those on muddy bottom sediments showed an increase of 4.8. As for the red sea cucumbers, the weight increase rates in the sandy and in the muddy sediment categories were 4.3 and 3.0 respectively which is less than for the green sea cucumbers in both categories. 140

The correlations between the numbers of specimens transplanted and their growth in tests III are shown respectively in Tables 34, 35. Maximum growths of 6.0 on the sandy bottom matters and of 7.0 on the sand-and-mud bottom matters were seen from early November to mid-April of the following year. Within the approximate 5 months (growth period) the weights at transplanting time had increased 7 - 8 times.

In such places strongly affected by land waters, the green sea cucumbers show more growth than the red sea cucumbers do. More particularly with regard to the green sea cucumbers, growth on the bottom sediments consisting mainly of mud where the volumes of organic carbon and nitrogen are higher tended to be superior to the growth on sandy sediments. Growth on the sand sediments in the test II was superior, but from spring to summer, a large amount of environmental animal species were present inside the crawls placed on the muddy sediments and it would seem that this was detrimental to the feeding conditions of the sea cucumbers.

C - Mass-growth of the green sea cucumbers

1. Monthly variations of the body wall weight composition of low-tide zone sea cucumbers

From August 1955 to August 1956, we gathered in Ehima, Atsumi peninsula, Aichi Prefecture specimens in the low tide zone where at high tide time the water depth is 10 - 80 cm. We gathered each time 42 - 337 individuals. The monthly variations in the body wall weight composition of the total of 1,014 beach sea cucumbers* is shown in Fig. 69.

One may discover around August white juvenile sea cucumbers of a 3 - 5 mm length and 0.1 - 0.5 g weight born in the same year and having no apparent body pigments yet attached to the calciphilous weeds growing on the reefs, or to the stalks and such of other weeds and ajimo. From November to December, their body walls grow to a 1 - 3 g size.

In Graph 69, the first peak with the mode of 1.3 g for body wall weight in October is shown by the group of juvenile sea cucumbers born in the same year. The second peak with the mode of 8.8 g for body wall weight corresponds to the 2-year group of retarded growth. The group of green sea cucumbers of that age is easily distinguished from the 2-year group by the fact that the green pigments of the body epidermis is brilliant and that their texture is soft.

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* note: The traders call "beach sea cucumber" the small sea cucumbers seen from the low tide area to the seaweed fields.

The group with the 1.3 - 3.8 g body wall weight appearing in October grew by March of the following year to a body weight of 6.3 g (average value). From late May until late June, the average body wall increased to 8.8 g. Later, by the end of August, virtually no growth is noted. 142

Thus, one full year after birth, the body wall weight of the green sea cucumber is 8.8 g. This may be confirmed by the fact that at the time of abundant generation of green sea cucumbers in the fishing grounds of the sites in question in 1957, the average body wall weight after 1 full year was about 10 g.

As Fig. 69 shows, no individuals with body wall weight of more than 40 g are observed throughout the year in the low tide area of the coast. Another particular phenomenon is the presence throughout the year of a small-type group with a body wall weight around 3.8 g. The absence of large-type groups in the low-tide zone means that the sea cucumbers disperse towards the offshore waters as they grow. It seems that the individuals remaining in the low-tide zone are left behind instead of dispersing as they are small-type individuals exhibiting no growth.

2. Monthly variations of the body wall weight composition among the offshore sea cucumbers.

Fig. 70 shows the monthly variations in body wall weight composition among the specimens collected about 5 times with a dragnet from

August 1955 to July 1956 at each of the 1 - 15 vertical range strata including the coastal low-tide zone, at regular equal distances. Each time 306 - 570 individuals were gathered, the total used being 2,001 individuals. As a reference, the material registered on February 15, 1957 in Momotori, Mie Prefecture represents 1,076 individuals.

Fig. 70 shows that the body wall weight composition of each month reveals 2 - 3 peaks which seem to indicate the particular age groups. We consider that the body wall weight composition of the various age groups exhibit regular distributions. We analyzed the frequency distribution of the body wall weight composition into several regular distributions, using normal probability sheets, and assumed that the various groups corresponded to the respective age groups. We disregarded the growth differences between females and males.

On August 14, 1955 we noted 2 groups having respectively body wall weights of 2.5 - 22.5 g (average value: 10.2 g) and 22.5 - 122.5 g (69.4 g). When considering in conjunction with the growth results for the low tide zone sea cucumbers, we note that the first group corresponds to the 2-year group having just completed one year after generation, and that the 2nd group represents the 3-year group.

The October 24 body wall weights are divided into 3 groups viz. 2.5 - 22.5 (12.6 g), 22.5 - 82.5 g (50.2 g) and 82.5 - 162.5 g (116.7 g). 144
They seem to correspond respectively to the 2, 3, 4-year groups.

On December 9 we noted 2 groups with respective body wall weights of 2.5 - 37.5 g (21.2 g) and 37.5 - 137.5 g (83.1 g), and on March 14, 3 groups with respective body wall weights of 2.5 - 12.5 g (6.8 g), 12.5 - 97.5 g (48.8 g), and 97.5 - 182.5 g (134.8 g). The first group of March corresponds clearly to the group of larval sea cucumbers born in the previous year having not yet reached one year.

On July 2, there were 3 groups having body wall weights of 2.5 - 22.5 (11.2 g), 22.5 - 127.5 g (76.8 g) and 127.5 - 222.5 g (171.6 g) respectively. They represent respectively the 2, 3, 4-year groups.

Although the years and fishing grounds are not the same, the specimens collected on February 15, 1957 in Momotori, Mie Prefecture were divided into 4 groups: 17.5 - 47.5 g (35.2 g), 47.5 - 117.5 g (83.8 g), 117.5 - 212.5 g (162.8 g) and 212.5 - 317.5 g (255.1 g). The low-tide zone individuals are not included. It thus seems that the first group corresponds to the 3-year group.

Fig. 71 shows the green sea cucumber growth curve obtained from the average body wall weight of the various year class groups within the monthly body wall weight compositions.

The green sea cucumbers grow from November to May (see Fig. 44). Their particular growth pattern reveals a drop in body weight taking place from June to October. More particularly, the growth during the first two full years coincides well with the results of the rearing tests conducted with crawls, and may for the present be regarded as adequate.

If on the basis of the above observations, one considers that the green sea cucumbers born in early June have after one year a body wall weight of 9 g, after two years one of 80 g, after three years one of 175 g and after four years one of 260 g, and if we convert these data to body length, total body wall weight,* we obtain 5.9 cm, 15.5 g for one full year, 13.3 cm, 122.4 g for 2 full years, 17.6 cm, 307.1 g for 3 full years and 20.8 cm, 472.5 g for 4 full years.

D - Decrease of body weight in summer

Growth of green sea cucumber is noted at and below the water temperature of 19°C. If the temperature is higher, there occurs a drop in body weight. In the aforementioned growth tests conducted in tanks with running water (Table 33, Fig. 65), the growth reached a peak value in mid-May followed by conspicuous decrease in body weight up to early October. The decrease rate shows 49 - 65% (average: 55.6%) for small sea cucumbers, 56 - 62% (59.1%) for medium sea cucumbers. In the growth tests 146
conducted with crawls also (Fig. 66), there occurred a weight drop of 39 - 67% from the time of maximum growth until late August.

The above results suggest that in enclosed environments, the sea cucumbers are exposed to high temperatures more often than they should and that they suffered an excessive loss in weight. However, the green sea cucumbers reflect the growth and aestivation periods of the natural conditions. Fig. 71 shows clearly the plus → minus → plus growth

*Computed from the relational formula (Table 6) of August (Ehima).

iterations. From June to early October, almost no weight loss is seen in the table for the 2-year group. In the 3-year and 4-year groups however, the weight losses are 40.0% and 33.7% respectively.

The green sea cucumbers growth is thus showing a close relationship agreeing exactly with the annual variations of the alimentary canal. The body weight decrease in the high water temperature period seems to be caused by nutrition regression due to the shrinking of the alimentary canal concomitant to the high water temperatures.

Meanwhile, we transplanted 1, 2, 4, 7, 11, 16 small green sea cucumbers of an average body weight of 10 - 23 g each in porcelain water tanks of a 30 L capacity in May - October (spring - summer period) and December - March (winter - spring period). They were kept without any feeding. Fig. 72 shows the observed decreases in weight.

It is shown that the rate of weight decrease caused by the absence of feeding is closely related to the density at which the individuals are kept. At the beginning, the effect of density is small but it increases as the days go by. The rate of body decrease grows together with the density. The effect of the season (water temperature) is unclear. After 72 -76 days of no feeding during the spring - summer period and the winter - spring period, we observed a 38 - 65% weight decrease.

E - Density and growth

From March 1956 to August of the same year (spring - summer period), we spread sandy or muddy bottom sediments in crawls of a 5,000 cm^2 area. We set the sea cucumber densities in the various crawls at 9 (6 green sea cucumbers and 3 red sea cucumbers), 18 (12 : 6), 36 (24 : 12), 72 (48 : 24) individuals. From August 1956 to May 1957 (fall - spring period) we set the accommodation densities at 6 (3 green sea cucumbers, 3 red cucumbers), 12 (6 : 6), 24 (12 : 12), 44 (24 : 20) individuals. The growth data for these two periods are given in the Tables 36, 37 and in the Graphs 73, 74 respectively.

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Tables 34, 35 show the growth results obtained when adopting with green sea cucumbers only accommodation densities of 1, 2, 3, 4 individuals in tests conducted from November 1957 to April of the following year (fall - spring period).

Table 36 and Fig. 73 show the growth in the various density sections in the spring - summer period. No growth is seen except for a 154
very small growth in the green sea cucumber low-density section. The rate of weight increase is inversely proportional to the accommodation density. More particularly, the red sea cucumbers showed uniformly a decrease in body weight except for an initial slight growth in the muddy bottom sediment section holding 9 individuals.

In the fall - spring period, good growth was observed in every section, except for some weight decrease noted in the early high water temperature period. However, the rate of weight increase was in this case also inversely proportional to the accommodation density (Table 37, Graph 74).

Figs. 75, 76 show the relationship between accommodation density and average total weight per individual. A rectilinear relationship is observed between the various logarithms. This shows that as the accommodation period (growth period) lengthens in the spring - summer period, the body weight decreases noticeably in the high-density sections and that the body weight increases conspicuously in the fall - spring period in the low-density sections.

Figs. 73, 74 show the volumes of organic carbon and of nitrogen contained in the bottom sediments of the crawls by various densities. 155
There appears no rectilinear relationship between growth and feeding volume. There is conspiciously little excretion in the high-density sections, and in relative terms the feeding volume goes decreasing. It would seem that because of the increased accommodation density, feeding obstruction takes place. One may believe that this is caused by the fact that the bottom sediments become reduced due to the sedimentation of organic matters consequent to high density as well as by a lack of oxygen. Yet, clear differences in growth are noted between the various densities even at low accommodation densities of 1 - 4 individuals (Tables 34, 35). This suggests that there could be some mutual biological interference between the sea cucumbers.

F - Considerations on the optimum density of transplanting 156

Onr may say that within the range of 72 sea cucumbers contained inside crawls having an area of 5,000 cm² the sea cucumber death rate during the rearing period is extremely small (Tables 36, 37). This can be seen from the death situation during the spring - summer period which is particularly unfavorable to growth. The change in the number of individuals in the fall - spring period of Table 37 was due to escape 157 consequent to breakage of crawls.

Therefore if one may consider the growth amounts during the various seasons of Table 37 as the growth amounts with the early accommodation densities, then the values obtained by multiplying the average total weights at the various periods by the early accommodation density will correspond to the sea cucumber yields at the various periods. Figs. 77, 78 show the relationship between the so obtained sea cucumber accommodation densities and the yields.

One observes rectilinear relationships between the various logarithms of the sea cucumber accommodation densities and of the yields. In the spring - summer period, one observes some yield increases within the low density sections during the early growth season of the green sea cucumbers. In the high-density sections however, there is a decrease from the beginning. There is also a decrease starting from the beginning in the red sea cucumber low-density sections. For both the green and the red sea cucumbers, there is an obvious decrease in yield in the high-density sections.

In the fall - spring period, there is for both the green and the red sea cucumbers a gradual yield increase up to the maximum growth period of mid-May. The increase is particularly remarkable in the low density section. The results show that there is not much difference in the yield of green sea cucumbers within the range of 3 - 24 individuals accommodated per 5,000 cm^2.

Tables 34, 35 show with regard to green sea cucumber growth in the sandy sediment zone a weight increase rate (total weight) of 6.0 for the 1-individual section, of 4.5 for the 2-individuals section and 3.2 for the 3-individuals section. The yields for the 2, 3 individuals sections indicate respectively increases only 32% and 53% higher than the yield for the 1-individual section. Therefore, the weight increase rate in the sand-and-mud sediment zone showing good growth is 7.0 for the 1-individual section, 6.0 for the 2-individuals section, 4.6 for the 3-individuals section and 4.7 for the 4-individuals section. The yields of 2, 3, 4 individuals section indicate respectively increases of 73%, 91%, 133%. The difference of weight increase rates in the sandy bottom sediment zone and in the sand-and-mud bottom sediment zone mean sea cucumber productivity in the regions in question. One sees that the release density must be taken into account when performing intensive sea cucumber release in sea waters. However, since the weight increase rate of 6.0 - 7.0 of the 1-individual section shown here is roughly equivalent to the growth amount under natural conditions, one may say that an accommodation density of at most 1 individual per 5,000 cm^2 provides a norm for appropriate release volume.

It was estimated that in the green sea cucumbver fishing grounds of Ehima, Atsumi peninsula, the natural living density at the sea cucumber fishing period of 1956 was 0.007 - 0.193 individuals (average of 0.07 individuals) per 1 m^2 (Table 10). Ewatari* (1954) reported a living density of 0.26 - 0.48 individuals per 1 m^2 in the Mimuro district of the Nanao bay in the Ishikawa Prefecture. Yamanchi reported habitat densities of 0.28 - 0.51 individuals (0.44 individuals) for Holothuria atra (black sea cucumber) off the Palau islands, and 0.047 - 0.114 (0.07 individuals) for Holothuria vitiensis. Such natural habitat densities are still far away from the aforementioned appropriate release volume and one may say that in the natural conditions there may still be room for increased production.

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*Translator's note: Reading probable but not quite certain; same hereafter for * following person's name.

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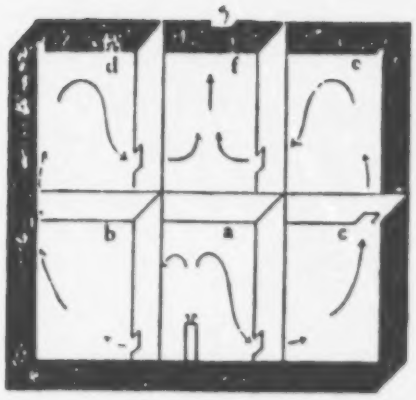

Fig. 64 - View of the tank and its section being used for rearing of the green sea cucumber. Arrows represent the direction of water current. a: No bottom sediment. b: Sandy bottom sediment. c: Muddy bottom sediment. d: Sandy bottom with green algae. e: Sandy bottom with rice-bran. f: Sandy bottom with fish-meal.

Table 33 - Growth of the green sea cucumber in the tank.

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大きさ Size	測定日 Date / 項目 Item	'86.XI.24 放養時 Releasing 尾数 No.	平均** 全体重 (g)	III. 2 (8 days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	III. 29(35days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	'87. II. 18 (86 days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	III. 19(115days) 尾数 No.	平均 全体重** (g)	増重率 Growth rate	V. 12(169days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate
小 (Small size)	無泥 No sediment	5	24.2	5	22.1	−0.087	5	28.0	0.157	5	44.4	0.835	5	61.0	1.521	5	96.0	2.967
	砂 Sand	5	22.2	5	23.8	0.081	5	30.8	0.387	5	47.0	1.117	5	60.4	1.721	5	70.6	2.189
	泥 Mud	5	20.2	5	18.5	−0.084	5	23.2	0.149	5	36.0	0.782	5	34.2	0.693	5	45.6	1.257
	砂+青海苔 Sand, green algae	5	20.4	5	24.9	0.221	5	34.2	0.676	5	47.6	1.333	5	56.0	1.745	4	55.0	1.235
	砂+米糠 Sand, rice-bran	5	20.2	5	20.6	0.020	5	29.2	0.446	5	19.8	−0.020	5	26.2	0.297	4	33.0	0.634
	砂+魚粉 Sand, fish-meal	5	21.8	5	22.7	0.041	5	30.8	0.413	5	30.6	0.404	5	38.6	0.771	5	54.0	1.477
中 (Moderate size)	無泥 No sediment	5	52.2	5	41.8	−0.199	5	48.7	0.067	5	63.4	0.215	5	68.2	0.307	5	84.2	0.613
	砂 Sand	5	51.6	5	44.0	−0.147	5	54.0	0.047	5	34.2	−0.318	5	50.2	−0.027	5	66.0	0.280
	泥 Mud	5	50.2	5	45.0	−0.104	5	50.8	0.012	5	50.8	0.012	5	53.6	0.065	5	52.2	0.040
	砂+青海苔 Sand, green algae	5	52.2	5	46.9	−0.102	5	53.4	0.023	5	43.6	−0.165	5	47.0	−0.100	5	45.0	−0.137
	砂+米糠 Sand, rice-bran	5	51.8	5	46.8	−0.097	5	47.2	−0.089	3	46.3	−0.106	3	47.0	−0.093	3	51.0	−0.015
	砂+魚粉 Sand, fish-meal	5	49.4	5	45.0	−0.089	5	54.0	0.093	5	42.6	−0.138	5	49.0	−0.008	5	61.4	0.243

* 底質と餌料 Sediments and food. ** Mean body weight (g).

Table 33 - Growth of the green sea cucumber in the tank.

大きさ Size	項目 Item * / 測定日 Date	VI, 4 (192days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	VII, 3 (221days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	VIII, 11 (259days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	IX, 12 (291days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate	X, 9 (318days) 尾数 No.	平均** 全体重 (g)	増重率 Growth rate
小 (Small size)	無底質 No sediment	5	67.2	1.776	5	50.4	1.083	5	42.0	0.736	5	41.6	0.719	5	35.3	0.459
	砂 Sand	5	54.4	1.450	5	37.6	0.694	4	35.0	0.577	4	35.3	0.586	4	36.0	0.622
	泥 Mud	5	33.6	0.663	5	25.6	0.267	5	20.8	0.114	5	20.2	0.000	3	17.3	−0.144
	砂＋青藻 Sand, green algae	4	51.7	1.534	4	36.0	0.765	3	34.7	0.701	3	36.0	0.765	3	36.7	0.800
	砂＋米糠 Sand, rice-bran	4	27.0	0.337	4	23.5	0.164	4	15.0	−0.257	4	17.0	−0.158	4	16.5	−0.183
	砂＋魚粉 Sand, fish-meal	5	43.4	0.991	5	29.6	0.358	5	22.4	0.028	5	24.7	0.133	5	19.1	−0.141
大 (Large size)	無底質 No sediment	5	57.2	0.096	5	43.2	−0.172	5	38.0	−0.272	2	40.0	−0.234	2	32.5	−0.381
	砂 Sand	5	47.6	−0.078	5	38.8	−0.248	5	33.0	−0.360	4	32.0	−0.380	4	28.5	−0.448
	泥 Mud	5	32.4	−0.355	5	26.2	−0.475	5	22.8	−0.546	1	23.0	−0.542	1	20.3	−0.602
	砂＋青藻 Sand, green algae	5	30.8	−0.410	5	27.6	−0.471	5	22.6	−0.567	4	18.0	−0.655	4	18.[illegible]	−0.665
	砂＋米糠 Sand, rice-bran	3	33.7	−0.349	3	29.0	−0.440	3	24.7	−0.523	3	24.2	−0.533	3	21.[illegible]	−0.597
	砂＋魚粉 Sand, fish-meal	5	48.6	0.016	5	42.4	−0.142	5	31.3	−0.366	3	31.7	−0.356	3	25.[illegible]	−0.480

* 底質と餌料 Sediments and food. ** Mean body weight (g).

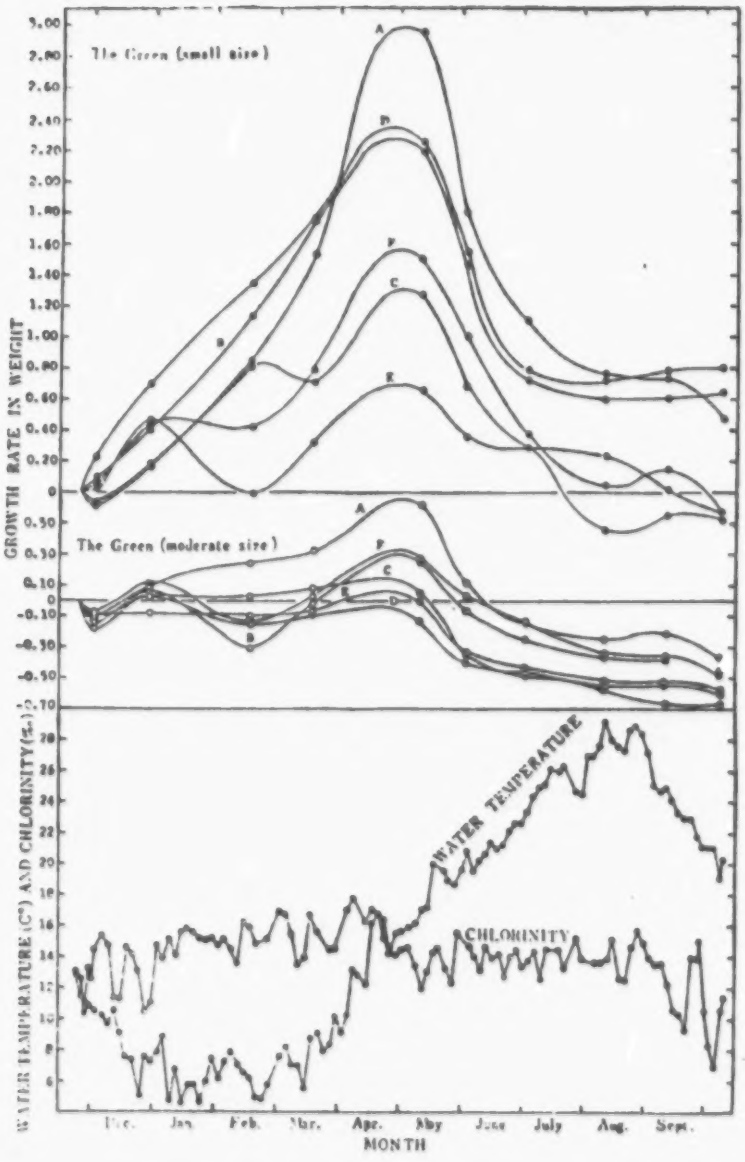

Fig. 65 - Growth of the green sea cucumber in the tank in relation to the water temperature and the chlorinity.

A: No bottom sediment.
B: Sandy bottom sediment.
C: Muddy bottom sediment.
D: Sandy bottom with green algae.
E: Sandy bottom with rice-bran.
F: Sandy bottom with fish-meal.

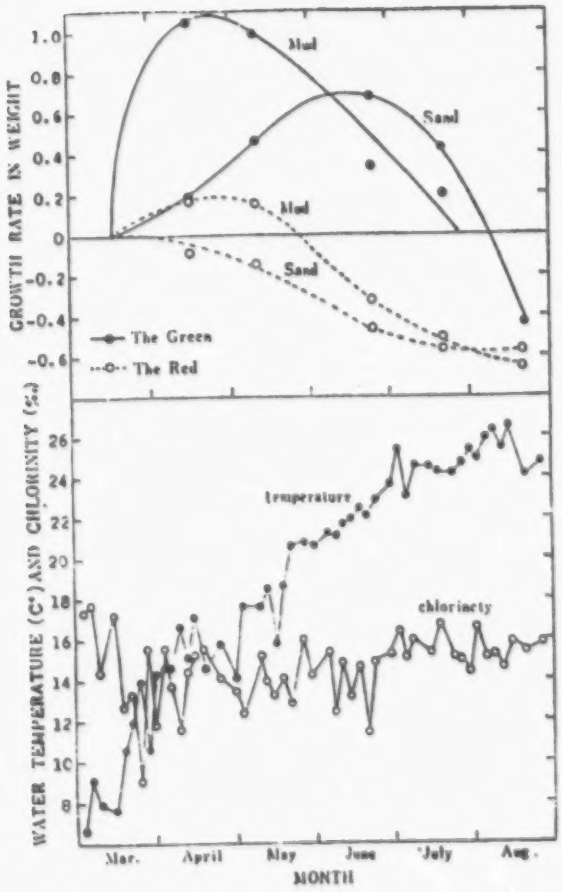

Fig. 66 - Growth of the green (solid circles) and the red (open circles) sea cucumber at the store box in relation to the water temperature and the chlorinity from spring to summer.

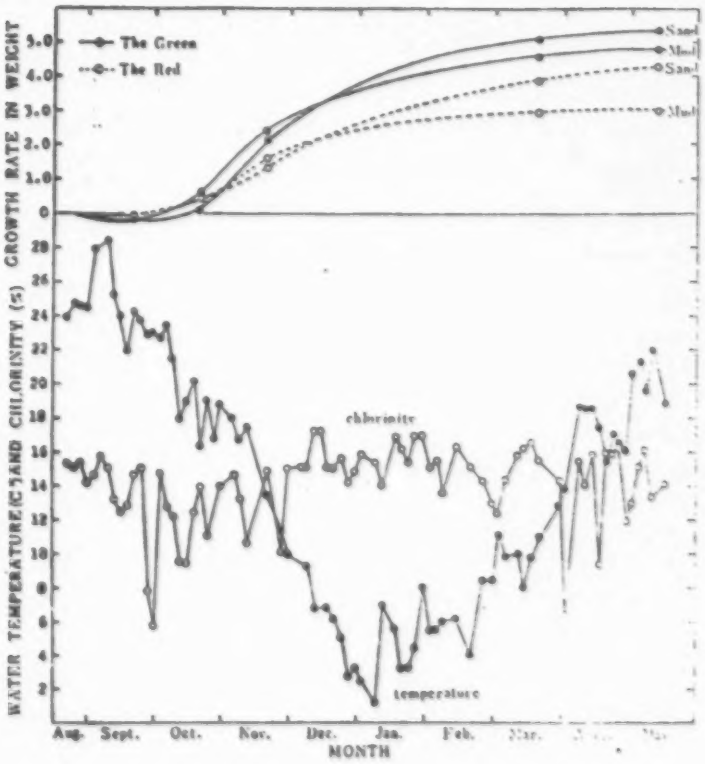

Fig. 67 - Growth of the green (solid circles) and the red (open circles) sea cucumber at the store box in relation to the water temperature and the chlorinity during autumn to spring.

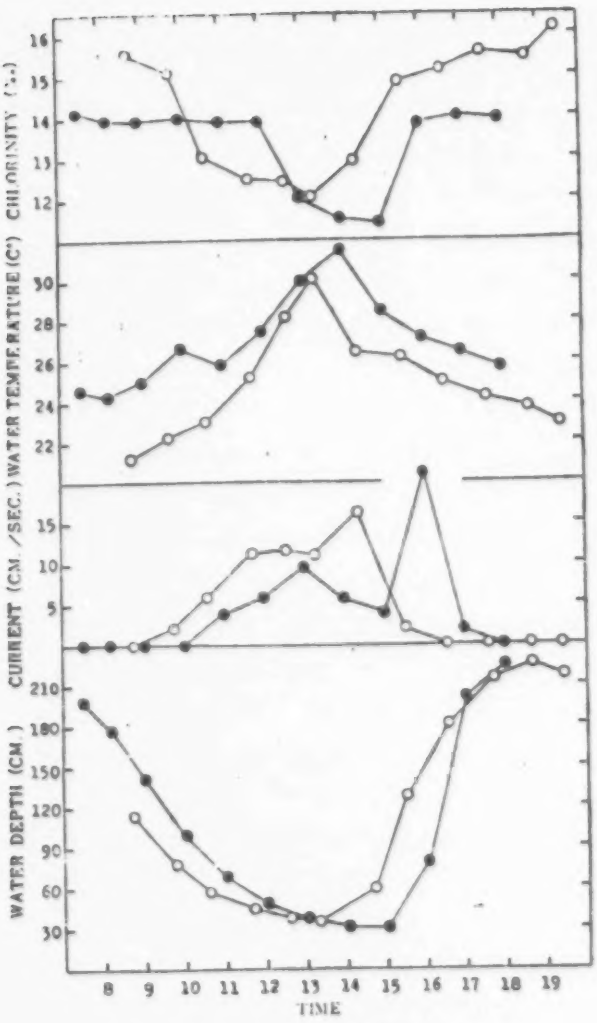

Fig. 68 - Examples of daily changes of environmental factors at the experimental station.
o: June 25, 1956
•: July 24, 1956.

Table 34 - Growth of the green sea cucumber in the store box. (Exp. III, 138 at the sandy bottom).

収容密度 Density (individ. no.)			1	2	3	4	2	2	1
生設面積 Area of store box (sq. cm.)			5000	5000	5000	5000	2000	2000	2000
収容時 Transplant Wo (gr.)	収容日 Transplanting date		1959, XI—4						
	全体重範囲	Range of body weight	18	14—17	14—18	14—18	14—17	98—104	206
	平均全体重	Mean body weight	18.1	15.1	15.5	14.9	15.4	102.0	206.0
	平均殻重	Mean weight of body wall *	10.6	8.9	9.1	8.8	9.1	60.0	121.1
	標準偏差 (全体重)	S.d. (body weight)	—	1.3	2.0	2.1	1.2	2.1	—
取り上げ Harvest W1 (gr.)	取り上げ日	Harvesting date	1960, IV—15						
	全体重範囲	Range of body weight	127.0	57—110	33—83	**	36—85	126—133	—
	平均全体重	Mean body weight	127.0	83.5	64.8		60.6	129.3	202.0
	平均殻重	Mean weight of body wall	63.3	40.3	31.3		27.4	63.3	103.0
	標準偏差 (全体重)	S.d. (body weight)	—	37.5	27.6		34.8	5.3	—
	標準偏差 (殻重)	S.d. (w. of body wall)	—	17.0	14.1		11.1	9.2	—
成長率 Growth rate (W1—Wo)/Wo	全体重	Body weight	6.017	4.530	3.181		2.935	0.268	−0.009
	殻重	Weight of body wall	4.972	3.528	2.440		2.011	0.055	−0.148
死亡率		Mortality	0	0	0		0	0	0

* 式から求めた値 Estimated value from the equation. ** 流失 The store box was swept away.

Table 35 - Growth of the green sea cucumber in the store box (Exp. III, at the sand-muddy bottom). 139

収容密度 Density (indiv. no.)			1	2	3	4	2	2	1
生簀面積 Area of store box (Sq. cm.)			5000	5000	5000	5000	2000	2000	2000
収容時 Wo (gr.) Transplant	収容日	Transplanting date	1959, XI—4						
	全体重範囲	Range of body weight	17	16—19	15—19	13—17	14—19	106—112	228
	平均全体重	Mean body weight	17.1	16.9	15.6	14.0	14.9	109.5	227.8
	平均殻重	Mean weight of body wall*	10.1	9.9	9.2	8.2	8.8	64.4	133.9
	標準偏差（全体重）	S.d. (body weight)	—	1.1	1.7	1.9	1.2	1.9	—
取り上げ時 Wt (gr.) Harvest	取り上げ日	Harvesting date	1960, IV—15						
	全体重範囲	Range of body weight	137.0	101—136	80—93	72—86	59—84	134—135	—
	平均全体重	Mean body weight	137.0	118.6	87.3	79.8	71.0	134.0	220.0
	平均殻重	Mean weight of body wall *	65.0	55.2	41.0	38.6	29.8	64.2	100.5
	標準偏差（全体重）	S.d. (body weight)	—	24.9	6.7	5.8	17.7	0.3	—
	標準偏差（殻重）	S.d. (w. of body wall)	—	11.7	1.7	2.1	5.7	1.2	—
増重率 Growth rate (Wt−Wo)/Wo	全体重	Body weight	7.012	6.018	4.596	4.700	3.765	0.224	−0.342
	殻重	Weight of body wall	5.436	4.576	3.457	3.707	2.336	−0.003	−0.249
斃死率		Mortality	0	0	0	0	0	0	0

* 関係式からの計算値 Estimated value from the equation.

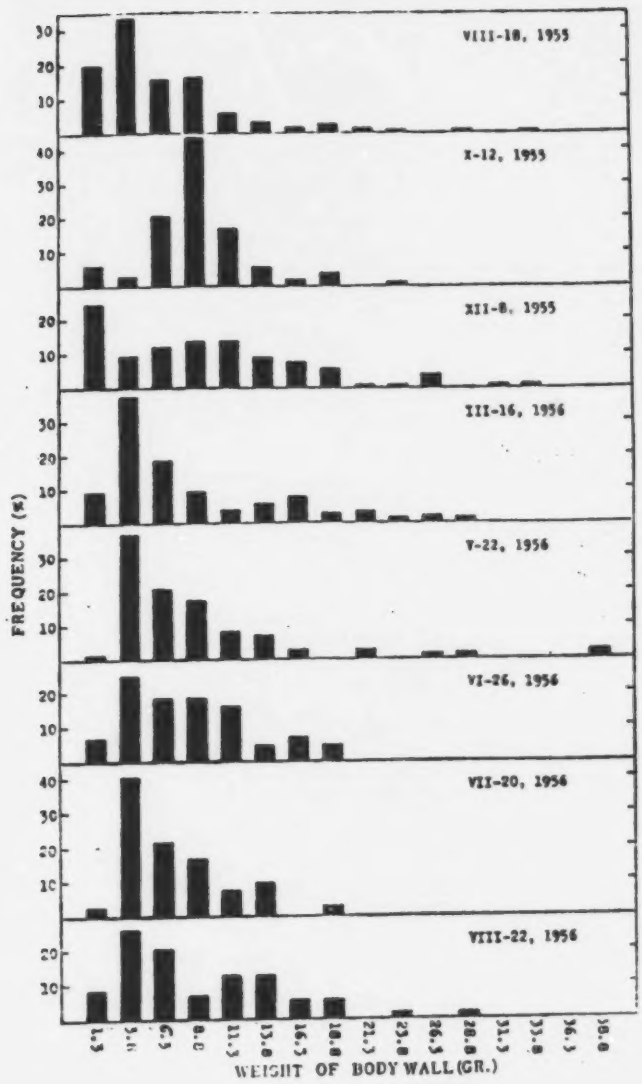

Fig. 69 - Monthly changes of the weight-frequency distribution of the young green sea cucumber at the low tide zone.

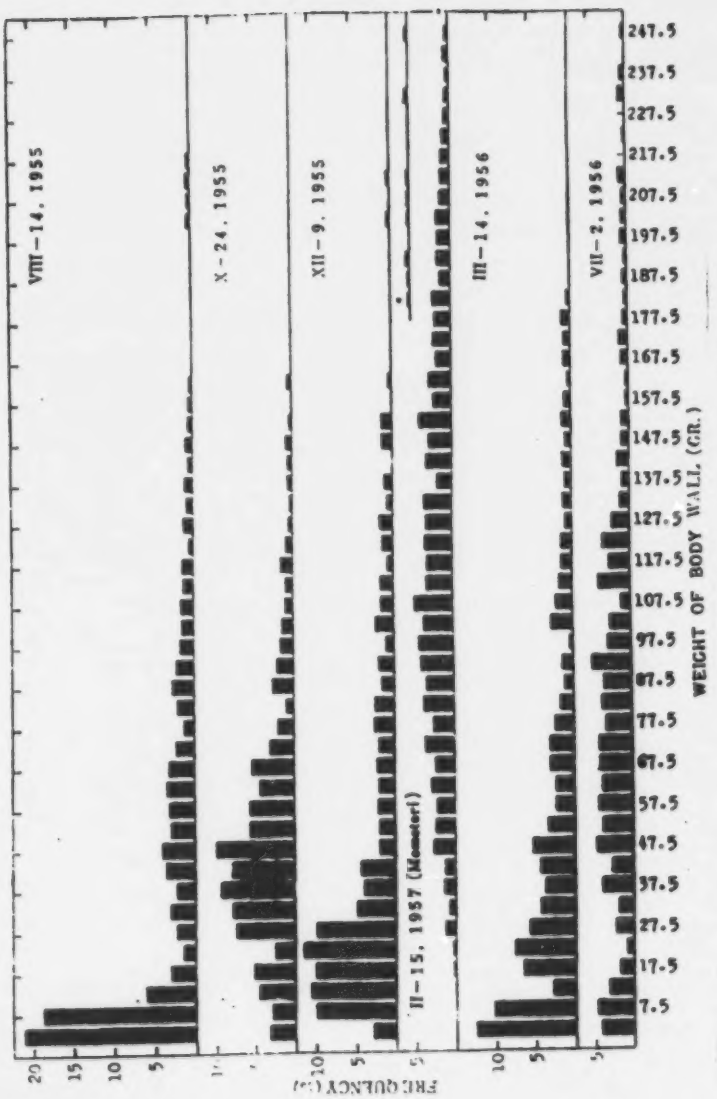

Fig. 70 - Seasonal changes of the weight-frequency distribution of the green sea cucumber at Atsumi region, Aichi Pref.

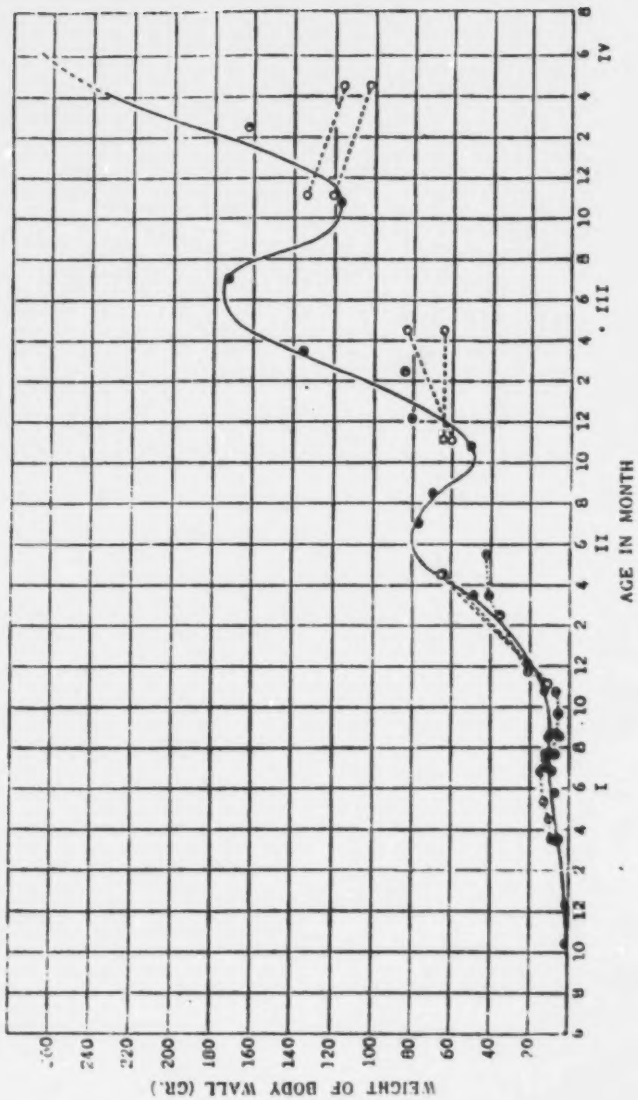

Fig. 71 - Growth curve of the green sea cucumber.
●: indicate the growth at Momotori, Mie Pref.
o, o: indicate the growth in the store box.

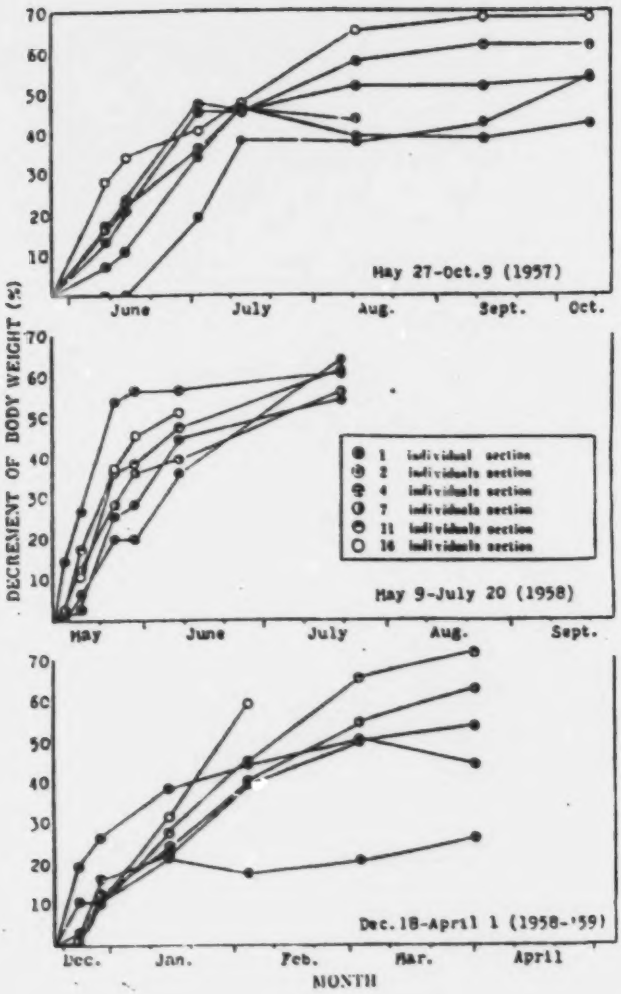

Fig. 72 - Decreasing rates of the body weight by the fast in the green sea cucumber.

Table 36 - Relation between the growth and the accommodation density of the green and the red sea cucumber, during spring to summer.

項目 Item		1956, 3—16 (放養時) Releasing			4—15 (30 days)				5—10 (55 days)			
		尾數 No.	1) 全体重 (g)	2) 全体重平均 (g)	尾數 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 增重率	尾數 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 增重率
アオナマコ The Green	砂 Sand	6	86.5	14.4	6	102.0	17.0	0.181	6	126.5	21.2	0.472
		12	205.0	17.1	12	204.0	17.0	−0.006	12	214.0	17.8	0.041
		24	491.0	20.5	24	332.0	13.8	−0.327	24	295.0	12.3	−0.400
		48	973.0	20.3	48	632.0	13.2	−0.350	48	490.0	10.2	−0.498
	泥 Mud	6	83.0	13.8	6	170.0	28.3	1.051	6	164.5	27.4	0.986
		12	201.0	16.8	12	230.0	19.2	0.143	12	239.0	19.9	0.185
		24	483.0	20.1	24	399.0	16.6	−0.174	24	322.0	13.4	−0.333
		48	963.0	20.1	48	770.0	16.0	−0.204	48	563.0	11.7	−0.418
アカナマコ The Red	砂 Sand	3	62.0	20.7	3	56.0	18.7	−0.097	3	53.0	17.7	−0.145
		6	115.0	19.2	6	97.0	16.2	−0.156	6	84.0	14.0	−0.271
		12	238.0	19.8	12	197.0	16.4	−0.172	12	161.0	13.4	−0.323
		24	667.0	27.8	24	436.0	18.2	−0.345	24	318.0	13.3	−0.522
	泥 Mud	3	67.0	22.3	3	78.0	26.0	0.166	3	76.5	25.5	0.143
		6	119.0	19.8	6	116.0	19.3	−0.025	6	102.0	17.0	−0.141
		12	267.0	22.3	12	230.0	19.2	−0.139	12	177.0	14.8	−0.336
		24	693.0	28.9	24	429.0	17.9	−0.381	24	356.0	14.8	−0.488

注 1) Body weight. 2) Mean body weight. 3) 增重率 Growth rate : (Wt−Wo)/Wo.

Table 36 - Relation between the growth and the accommodation density of the green and the red sea cucumber, during spring to summer.

7)	6)	4) 6—24 (100 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率	7—21 (127 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率	8—20 (157 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率
アオナマコ The Green	砂 Sand	6	144.0	24.0	0.667	6	122.5	20.4	0.417	3	24.0	8.0	−0.444
		12	194.0	16.2	−0.053	12	191.5	16.0	−0.064	1	6.0	6.0	−0.649
		24	248.0	10.3	−0.498	24	215.0	9.0	−0.561	22	122.0	5.5	−0.732
		48	362.0	7.5	−0.631	48	330.0	6.9	−0.660	36	147.6	4.1	−0.798
	泥 Mud	6	110.0	18.3	0.326	6	98.0	16.3	0.181	0			
		12	143.0	11.9	−0.292	12	152.5	12.7	−0.244	8	52.0	6.5	−0.613
		24	198.0	8.3	−0.587	*							
		48	274.0	5.7	−0.716	46	288.5	6.3	−0.687	40	148.0	3.7	−0.816
アカナマコ The Red	砂 Sand	3	33.0	11.0	−0.469	3	26.3	8.8	−0.575	1	11.5	11.5	−0.444
		6	37.0	6.2	−0.677	6	34.0	5.7	−0.703	3	19.0	6.3	−0.672
		12	86.0	7.2	−0.636	11	60.5	5.5	−0.722	11	49.0	4.4	−0.778
		24	167.0	7.0	−0.748	23	110.0	4.8	−0.827	10	45.5	4.6	−0.835
	泥 Mud	3	44.0	14.7	−0.341	3	32.5	10.8	−0.516	2	19.0	9.5	−0.574
		6	48.0	8.0	−0.596	6	46.0	7.7	−0.611	4	24.2	6.1	−0.692
		12	76.0	6.3	−0.717	*							
		24	140.0	5.8	−1.799	23	122.0	5.3	−1.817	20	89.0	4.5	−0.844

注 1) Body weight. 2) Mean body weight. 3) 増重率 Growth rate : (Wt−Wo)/Wo. 4) Date. 5) Item.
6) Sediment. 7) Forms.

* 生簀破損してナマコが逸散する The store box was broken.

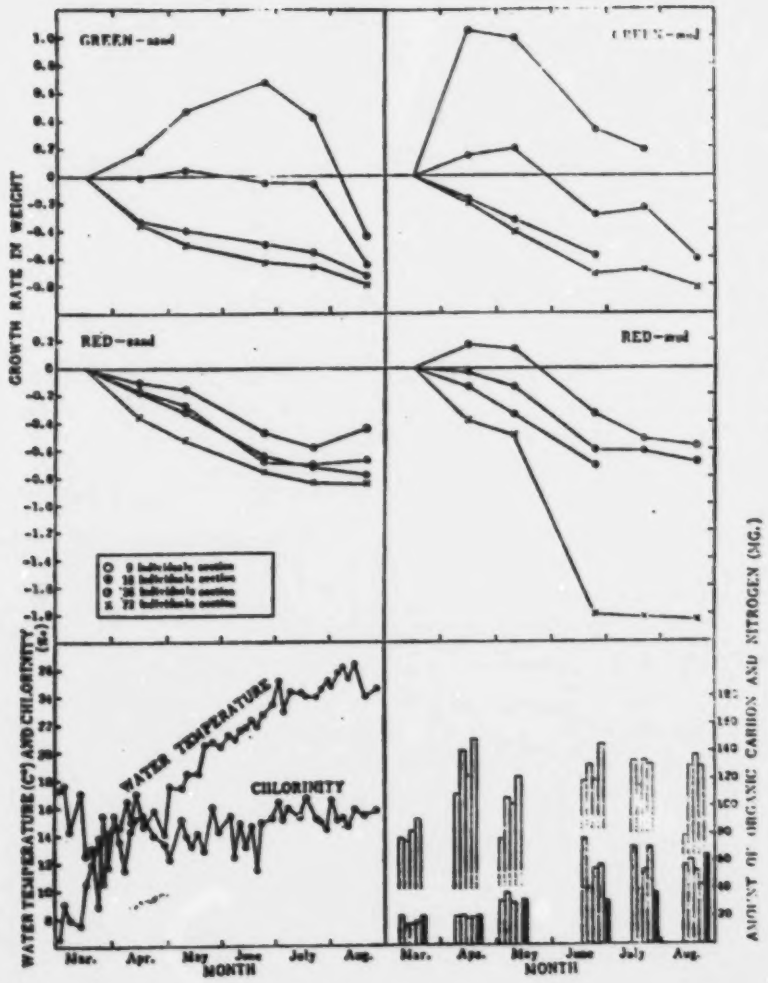

Fig. 73 - The growth rate with relation to the accommodation density of the green and the red sea cucumber, during spring to summer.

Table 37 - Relation between the growth and the accommodation density of the green and the red sea cucumber, during autumn to spring. 151

4) / 5) / 7)	6)	1956. 8—23 (放養時) (Releasing) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	9—20 (28 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率	10—21 (39 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率
アオナマコ The Green	砂 Sand	3	33.0	11.0	3	28.0	9.3	−0.155	3	36.5	12.2	0.109
		6	60.0	10.0	6	46.0	7.7	−0.239	6	88.0	14.7	0.470
		12	126.0	10.5	12	104.0	8.7	−0.171	12	192.5	16.0	0.524
		24	238.0	9.9	23	163.5	7.1	−0.283	21	261.5	12.5	0.263
	泥 Mud	3	34.5	11.5	3	29.0	9.7	−0.157	3	57.8	19.3	0.678
		6	62.5	10.4	6	44.5	7.4	−0.288	6	82.0	13.7	0.317
		12	126.0	10.5	12	91.0	7.6	−0.276	12	142.0	11.8	0.124
		24	224.0	9.3	23	145.5	6.3	−0.323	23	271.0	11.8	0.269
アカナマコ The Red	砂 Sand	3	35.0	11.7	3	30.0	10.0	−0.145	3	52.0	17.3	0.479
		6	66.0	11.0	6	57.5	9.6	−0.127	6	104.0	17.3	0.573
		12	149.5	12.5	12	135.0	11.3	−0.096	12	219.0	18.3	0.464
		20	292.0	14.6	20	272.5	13.6	−0.068	16	290.0	18.1	0.240
	泥 Mud	3	38.0	12.7	2	24.0	12.0	−0.055	2	40.0	20.0	0.575
		6	63.0	10.5	6	58.5	9.8	−0.067	6	99.0	16.5	0.571
		12	138.0	11.5	8	106.0	13.3	−0.157	6	120.0	20.0	0.739
		20	322.0	16.1	20	282.0	14.1	−0.124	17	333.5	19.6	0.217

注 1) Body weight. 2) Mean body weight. 3) Growth rate. 4) Date. 5) Item. 6) Sediment. 7) Forms.

Table 37 - Relation between the growth and the accommodation density of the 152 green and the red sea cucumber, during autumn to spring.

7)	6)	4) 11—20 (89 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率	1957, 3—28 (217 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率	5—14 (264 days) 尾数 No.	1) 全体重 (g)	2) 全体重平均 (g)	3) 増重率
アオナマコ The Green	砂 Sand	2	70.0	35.0	2.182	2	134.2	67.1	5.102	2	140.0	70.0	5.364
		6	139.0	23.2	1.320	6	185.4	30.9	2.091	6	172.0	28.7	1.870
		12	222.5	18.5	0.762	11	220.0	20.0	0.903	11	205.0	18.6	0.771
		7	112.0	16.0	0.616	5	89.0	17.8	0.800	1	17.0	17.0	0.717
	泥 Mud	3	117.5	39.2	2.409	3	187.5	62.5	4.435	3	198.6	66.2	4.753
		6	112.0	18.7	0.793	6	211.8	35.3	2.393	6	220.0	36.7	2.529
		10	178.0	17.8	0.695	10	252.0	25.2	1.393	9	215.0	23.9	1.276
		22	301.0	13.7	0.473	20	273.0	13.9	0.491	18	205.0	11.4	0.225
アカナマコ The Red	砂 Sand	3	82.0	27.3	1.333	2	111.8	55.9	3.775	2	123.0	61.5	4.256
		6	147.0	24.5	1.227	6	223.8	37.3	2.392	6	224.0	37.3	2.391
		11	223.0	20.3	0.624	12	286.8	23.9	0.913	12	292.0	24.3	0.944
		13	175.5	23.5	0.610	5	125.0	25.0	0.713	1	24.7	24.7	0.690
	泥 Mud	2	66.0	33.0	1.598	2	98.8	49.4	2.892	2	111.0	55.5	3.370
		3	58.0	29.0	1.762	5	148.5	29.7	2.825	5	194.0	38.8	2.695
		6	137.5	22.9	0.991	7	193.2	27.6	1.393	7	192.0	27.4	1.388
		19	446.0	23.5	0.460	18	443.8	24.6	0.527	18	448.0	24.9	0.547

1) Body weight. 2) Mean body weight. 3) Growth rate. 4) Date. 5) Item. 6) Sediment. 7) Forms.

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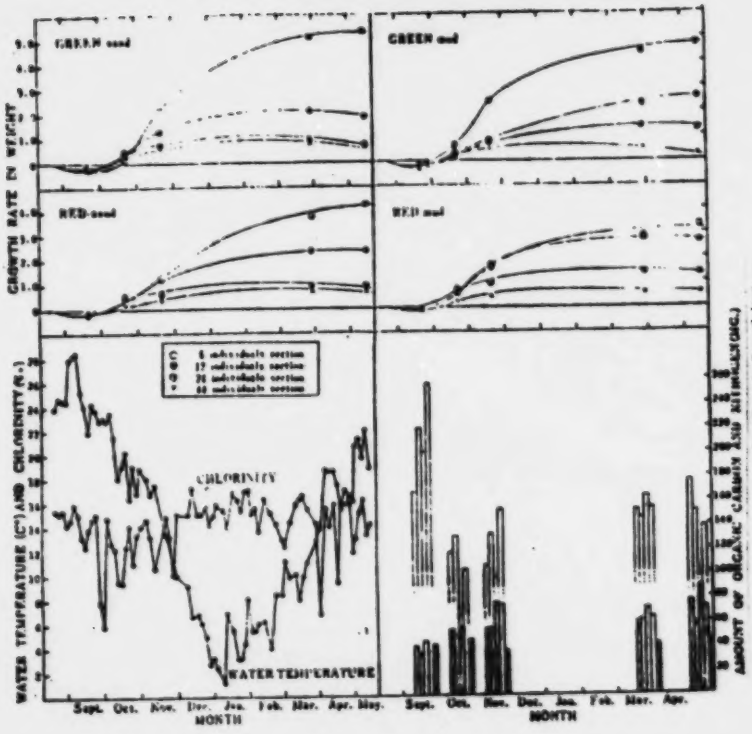

Fig. 74 - The growth rate with relation to the accommodation density of the green and the red sea cucumber, during autumn to spring.

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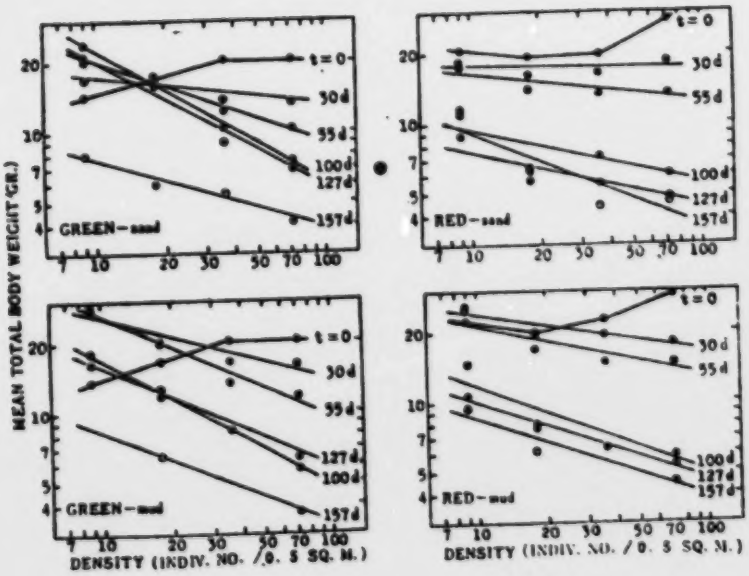

Fig. 75 - Relations between the accommodation density and the growth of the green and the red sea cucumber, during spring and summer.

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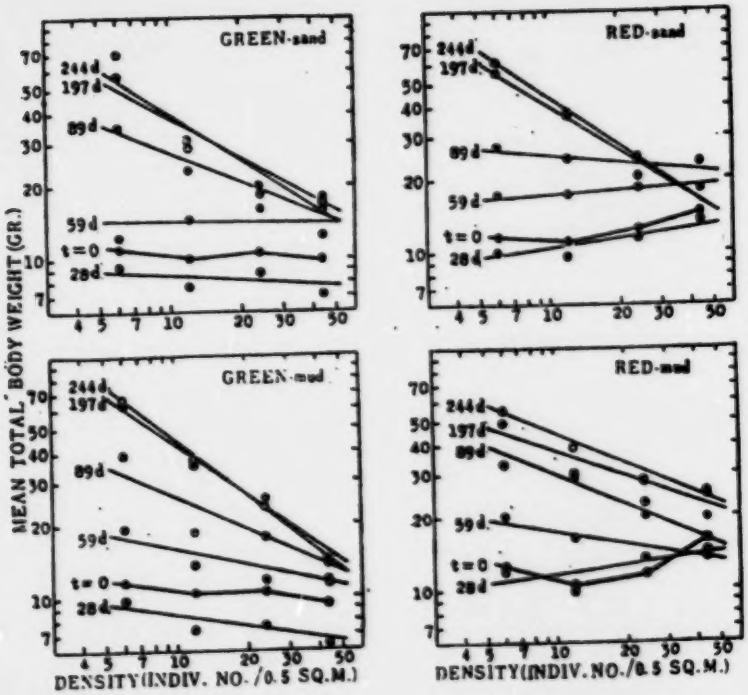

Fig. 76 - Relations between the accommodation density and the growth of the green and the red sea cucumber, during autumn to spring.

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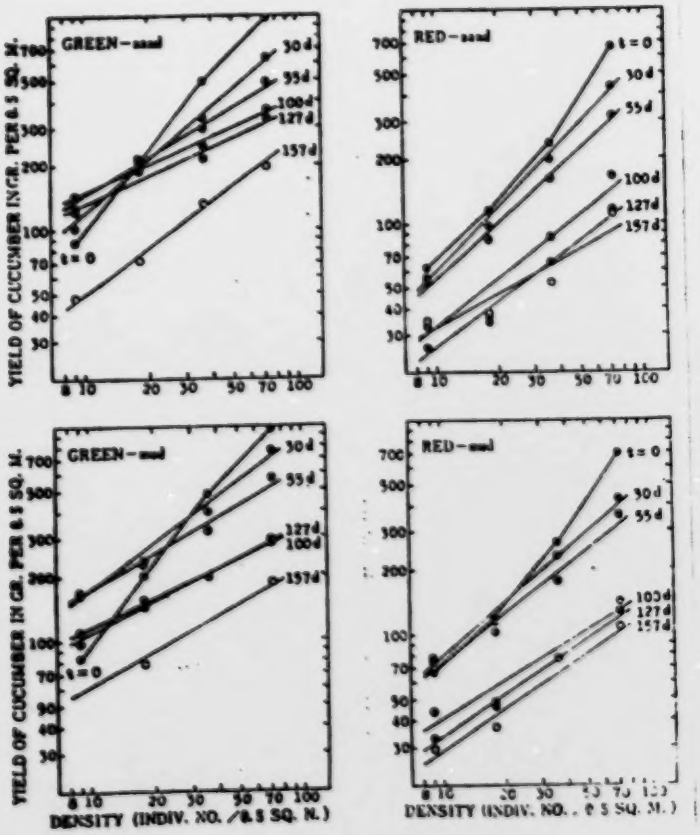

Fig. 77 - Relations between the accommodation density and the yield of the green and the red sea cucumber, during spring to summer.

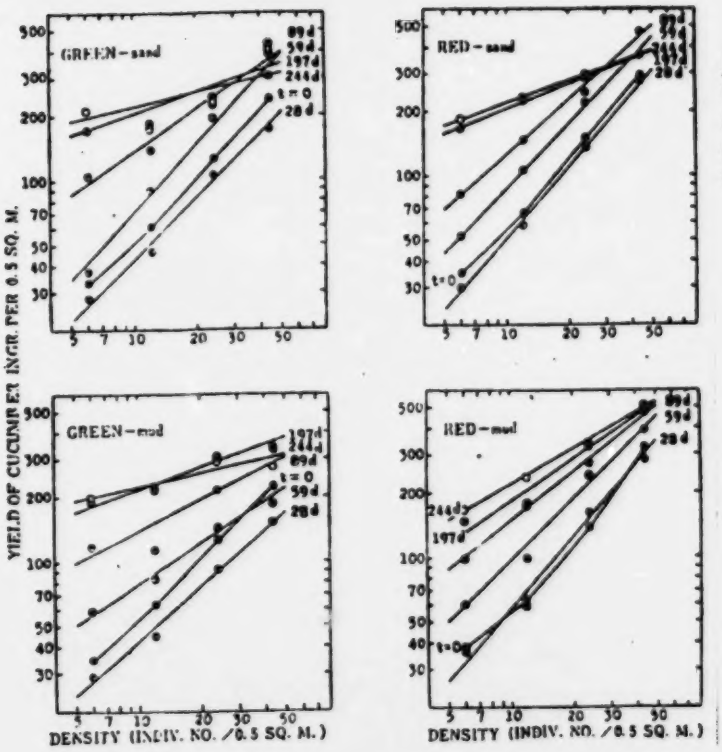

Fig. 78 - Relations between the accommodation density and the yield of the green and the red sea cucumber, during autumn to spring.

Chapter 14 - Tagging and the crawling activity 167

A - The tagging of sea cucumbers

To tag green and red sea cucumbers, one passes laterally through the dorsal part of the sea cucumber a thin hollow vinyl string, a nylon thread, a cotton thread, a flax thread or surgical catgut and the like which is tied afterwards. One tried also to cut open the dorsal part, to pass a thread from the inside to the outside and attach a small shell button. However the sea cucumber body tissues that come in contact with foreign matters disintegrate gradually so that the foreign matter is eliminated after which the tissues are regenerated. With this tagging methods the tags will rarely remain in place for up to 2 - 3 months and no practical tagging value could be noted.

In the former chapter, we explained that the scar left by the cutting open of the back could be used as a tag mark. We released in June to be reared in fishing grounds green cucumbers whose back had been cut open vertically along 2 - 4 cm. It was possible to recognize clearly the healed scars of the inflicted wound in numerous individuals picked up in February of the following year (8 months later). We show in Fig. 81 examples of identifiable individuals. Some individuals could be identified with relative ease whether the cut scar was extremely clear, whether the scar had concentrated into 1 dot where the body pigment was different or whether the body tissues were to a degree disarranged. There were other various stages whereby identification was more or less or hardly possible. It seems that the differences are not based on the initial cut conditions.

Green sea cucumbers never die when a cut of about 1/3 the size of the body length is made in the back-abdomen, and one may say that by making the cut somewhat large, one obtains a quite satisfactory tag.*

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B - Crawling activity

About the crawling mode of Stichopus panimensis, Parker (1921) was of the opinion that it was of a "direct monotoxic type" similar to the crawling seen in gastropodes, green and red sea cucumbers carry out crawling by the motion represented in Fig. 82. The body is first entirely extended (Fig. 82 A), then shrinks from the rear so that the rear end advances (Fig. 82 B). The contraction of the rear end is transmitted to the front part in an undulating fashion, and simultaneously, the tube feet which were attached to objects become successively detached, starting from the back and reach the front tube feet (Fig. 82 C, D). Thereafter, the part more or less at the back of the front part of the body becomes the 169
fulcrum, the front part of the body extends toward the front, and we have the situation seen in Fig. 82 A (Fig. 82 E, F). Crawling is performed through iterations of such motion.

In a water tank with sand spread on the bottom, crawling by the green sea cucumber is as represented in Table 41. The speed per hour is 497 - 710 cm (average: 583.7 cm). The distance covered in about 10 min

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*Note: It seems that if the cut is large, healing consumes much body volume; with an opening cut that healed after 7 days at the early June water temperature (19.0 - 22.0°C), the early body wall weight was observed to decrease by 3 - 29% (average of 19.7%).

is 1 m. This is somewhat faster than for the 1 m distance covered by Stichopus panimensis in about 15 min. Yamauchi (1941) examined the range of the 24 h wandering by Horothuria atra (black sea cucumber) and Stichopus variegatus (agemushi). He estimated that the range was about 5 m in places abundant in organic matters and with plenty of food strewn on the sea bottom, that the range was about 15 m in places where food was not so abundant, and that it reached a maximum of about 50 m in places where food was scarce. The results of Table 41 show that green sea cucumbers are able to travel a 108 - 170 m linear distance (average of 140 m) per day. It is expected that in places with particularly unfavorable living conditions, the travelling range will be quite considerable within a long period of time.

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Chapter 15 - Aestivation

Mitsukuri (1903) observed with regard to the green sea cucumbers of Kanazawa, Kanagawa Prefecture that the individuals having completed spawning in mid-July moved under rocks or in other dark places such as hollows, stopped feeding, contracted their bodies which hardened somewhat to become inactive during the high-temperature water period of the summer, and that they became active again as the water temperature dropped. He called "summer sleeping" the inactive condition seen during the high-temperature water season of the summer.

Later Tokuhisa reported with regard to the green cucumbers of the Nanao Bay, Ishikawa Prefecture that the critical water temperatures for the

start and end of aestivation was 20°C, that aestivation began at a 19 - 22°C water temperature and ended at 18 - 23°C in Hokkaido, the Miyagi, Aichi, Tokushima and Kagoshima prefectures.

Meanwhile, Kinoshita - Tanaka (1939), Kinoshita - Shibutani (1939) reported seeing no aestivation among the sea cucumbers of the Hokkaido. Sang - Oshima (1961) pointed to differences in the aestivation of green and of red sea cucumbers, reflecting their particular characteristic ways of coping with high water temperatures.

The life cycle of the green and of the red sea cucumbers reveals a regular annual periodicity with two polar periods corresponding to the high water temperature period in the summer and to the low water temperature period in the winter. More particularly with regard to the aestivation phenomenon seen in the high water temperature season, it cannot be contested from a physiological and ecological viewpoint, that there exists indeed one particular temporary period.

The only spare writings about the aestivation of the green and of the red sea cucumbers are the observations made by Mitsukuri, and Tokuhisa. Nothing precise is known about aestivation itself. This is why we consolidated all the sea cucumber ecological study results explained so far in the various chapters, and why we discussed the aestivation phenomenon on the basis of the seasonal changes noted in the somatic components of the green and of the red sea cucumbers. Our results are presented hereunder.

A - Degeneration of the alimentary canal in the period of aestivation.

On the basis of the seasonal variations seen in the alimentary canal and in the volume of respiratory tree of the green sea cucumbers, we divided the life cycle into 4 periods, that is, the active period, the early aestivation period, the aestivation period, and the recovery period. As we explained in Chapter 7, one notes several alimentary canal phases responding to the above periods, that is, growth, regression, complete regression and recovery. These phases show results in good agreement with the variations in the ingestion amounts and in the growth volumes during the year. 171

The green sea cucumber active period is noted to coincide with water temperatures at or below 17.5 - 19.0°C. At 8 - 10°C or lower, the alimentary canal develops to its maximum size. Water temperatures of 17.5 - 19.0°C or higher tend to hinder the growth of the sea cucumbers. Even if we consider that the recession of the alimentary canal observed in the period going from the maximum winter growth seen in the reproduction group to late May is due to the two-phase alternate conversions of feeding and reproduction and growth, it is also certain that the recession of the alimentary canal seen in late May in the immature group may be considered as a growth impediment caused by the rise in water temperature. The retrogression of the alimentary canal is still furthered later as the water temperature continues to rise. At water temperatures of 24.5°C and higher the sea cucumbers do not fail to hide. They go under rocks or penetrate hollows and spend the summer escaping somewhat the effect high water

temperatures. During this period the alimentary canal of most sea cucumbers retrogrades to a mere vestige and takes on the appearance of a thin cotton thread.

Fig. 83 shows the tissues of red sea cucumber alimentary canal retrograded during aestivation to a thin filament with less than 1 mm thickness in its widest part. Even though the alimentary canal is shriveled, the epidermis, muscle layers, the endodermis and other tissues of the dorsal-abdominal blood systems are preserved. Only most of the 173
mesogloea and connective tissues disappear. The alimentary canal is closed by the endodermis tissues of the colon and feeding becomes completely impossible.

As for feeding, the alimentary canal is virtually full of ingested matters by late May. However, as the alimentary canal retrogrades the amount of ingestion decreases. Finally no feeding is seen anymore and retrogression becomes total.

Table 42 shows the aestivation period retrogression and the recovery conditions observed among the green and the red sea cucumbers at the fishing grounds of Ikawazu, Ehima, Uzue of the Atsumi peninsula, Aichi Prefecture. From mid to end August, the proportion of individuals feeding almost to capacity even though their alimentary canal is obviously shrinking is 13% in the low tide zone (water depth: 10 - 80 cm), 18% offshore (water depth: 8 - 15 m), and those individuals whose alimentary canal has shriveled entirely to the shape of a thread represent 27% in the low tide zone and 52% offshore.

From mid-September, one month later to late September, the retrogression of the alimentary canal is still more advanced and more particularly among the beach sea cucumbers. The proportion of individuals filling their alimentary canal is 2 - 4% for both the low tide zone and the offshore waters. The proportion of individuals not feeding or whose alimentary canal is totally retrograded is 50% in the low tide zone and 76% in the offshore waters. In mid-October recovery is already visible. Totally shriveled alimentary canals are not seen anymore. In the low tide zone and in the seaweed fields (water depth: 2 - 3 m), 76 - 86% of the individuals are feeding quite well.

Thus, water temperatures of 17.5 - 19.0°C or higher hinder the normal activity of the sea cucumbers. With the approximate critical water temperature of 24.5°C, aestivation sets in. One may foresee that depending on the duration period of the limiting high water temperature and depending on the highest limiting water temperature reached during that period, the retrogression of the alimentary canal will show a great variety of stage phases. This may be surmised from the state of alimentary canal retrogression seen at different habitat depth within the same waters.

Young green sea cucumber individuals with body walls of 5 g or less show an alimentary canal recession during the high water temperature season but do not stop feeding. In the red sea cucumbers, the alimentary canal retrogrades regardless the size of the individual. They stop feeding and enter aestivation uniformly. These facts suggest that the temperature characteristics of the red sea cucumbers are more narrow than those of the green sea cucumbers.

B - Seasonal changes of composition of meat and the alimentary canal. 174

The life activity system of the red and of the green sea cucumbers is regulated by the water temperature. Evident cyclical changes are repeated according to variations in water temperature. One may consider with regard to the physiology of the somatic components that corresponding changes do somehow occur. From this vantage point we measured the seasonal changes in moisture, crude ash (ordinary method), crude fat (Soxhlet method) and total nitrogen volume (microkjehdal method) of the body walls and alimentary canal. The results are shown in Table 43 and Graphs 84, 85.

For the analysis, we used small individuals (body walls of 15 - 176
45 g) easy to obtain throughout the year so as to reduce the variations based on age. We used as body wall analysis material central body parts cut into rings and free from internal organs. As for the alimentary canals, we prepared materials free of the adjunct vascular system organs.

1. Variations in the body wall components

Table 43, Fig. 84 show that the volume of moisture is lower in the red sea cucumbers since it is 87.7 - 92.6% (average of 90.8%) in the 177
green sea cucumbers whereas it is 85.1 - 91.3% (average of 89.5%) in the red sea cucumbers. It decreases gradually throughout May, June, July and August in both the red and the green sea cucumbers. In accordance with the same annual period characteristics, it increases again throughout September - November.

Crude ash is 2.6 - 3.3% (2.9%) in green sea cucumbers and 2.5 - 3.3% (2.9%) in red sea cucumbers. There is no difference and little seasonal variations.

Crude fat is 0.1 - 0.9% (0.5%) in green cucumbers and 0.2 - 1.2% (0.6%) in red sea cucumbers. Total nitrogen is 0.5 - 1.0 (0.8%) in green sea cucumbers but 0.6 - 1.4% (0.9%) in read sea cucumbers. One sees that there tends to be a little more crude fat and total nitrogen in the red sea cucumbers.

The crude fat and total nitrogen increase from December in the body walls of the green sea cucumbers to reach a maximum in June, but decreases rapidly from September to November. In the red sea cucumbers the value is highest in September and decreases sharply througout September - November. Such variations of crude fat and total nitrogen in the body wall is seen to proceed in inverse proportion with the volume of moisture in the sea cucumbers. We see that the changes occur according to the increase and decrease of moisture during the aestivation and recovery periods.

2. Variations in the alimentary canal components

It is in November, during the recovery period, that the alimentary canal moisture is at its peak for both the green and the red sea cucumbers. Thereafter, it decreases gradually to reach a lowest value in March. In the following remaining period of the yearly cycle, moisture increases again. As the green sea cucumbers show 82.3 - 87.3% (85.1%) and

the red sea cucumbers 84.2 - 90.3% (86.8%), the latter show a somewhat higher moisture content (Fig. 85).

Green sea cucumbers show 1.8 - 2.8% (2.3%) crude ash changes while the red sea cucumbers show 1.6 - 2.7% (2.1%) changes. Green sea cucumbers tend to show somewhat higher crude fat contents as the contents are 1.2 - 1.7% (1.5%) in green sea cucumbers and 0.6 - 1.6% (1.4%) in red sea cucumbers. Total nitrogen is somewhat higher in the red sea cucumbers as the volume is 1.2 - 1.6% (1.4%) in green sea cucumbers and 1.1 - 1.8% (1.4%) in red sea cucumbers.

The volumes of crude ash, crude fat, total nitrogen in the alimentary canal also have a close relationship with the same moisture amounts as in the somatic components. As moisture decreases during the activity period, the volumes of those components increase. They decrease rapidly as the volume of moisture increases rapidly during the recovery period (sic: translator).

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C - Consideration on aestivation

One may among the factors inducing aestivation in the green and in the red sea cucumbers find internal factors, external factors as well as factors involving both. The internal factors originate from the biological 178
characteristics formed during long periods of time as well as from habits. Green or red sea cucumbers show no aestivation in cold seas or else, even if there is such phenomenon, it cannot always be easily identified with

certainty on the basis of the external appearances. It seems therefore that the aestivation factors are largely determined by external factor elements.

With regard to other animals, the causes inducing hibernation and aestivation are mainly considered to be the 3 elements of food shortage, light rays, and temperature. These elements could also be considered with regard to sea cucumbers (Johnson 1931 : Shimoizumi 1943). There is no question of food shortage for sea cucumbers. The increase in amount of light from spring to summer is closely related to the temperature. However the distribution state* of the aestivating sea cucumbers beneath large reefs suggests that the increase in amount of light is not a too important factor. Only the water temperature remains. As the sea cucumber aestivation is a particular phenomenon observed in the high water temperature season, one may easily surmise that water temperature is the most direct factor.

As we explained in the section on the seasonal variations of the alimentary canal, water temperatures of 17.5 - 19.0°C of higher involve clearly elements accelerating the shriveling and retrogression of the alimentary canal. The water temperature at which the green and the red sea cucumbers go into positive hiding in Atsumi, Aichi Prefecture and complete aestivation is around 24.5°C. In other words, during periods of such or higher water temperature, the condition in the deep sand and mud sediment

*Note: When aestivating beneath large rocks, the sea cucumbers gather in the most receded parts corresponding to the center of the rock. Such place seems to be suited to escape high water temperatures.

zone is unknown. The individuals whose habitat extends from the low tide zone to the relatively shallow places spend the high water temperature season mainly hidden beneath reefs or in hollows of the sea floor.

About both critical water temperatures to start and to complete aestivation Tokuhisa (1915) reports 20°C for the green sea cucumbers of the Nanao Bay (Ishikawa Prefecture). He reports about 2 weeks of aestivation in July in Hokkaido, gives 18°C and 21°C for the Miyagi Prefecture, 21°C and 18°C for the Aichi Prefecture, 19°C and 23°C for the Tokushima Prefecture and 22°C each for the Kagoshima Prefecture.

Meanwhile, Kinoshita - Tanaka (1939), Kinoshita - Shibutani (1939) reported that no aestivation was observed among the green sea cucumbers of Hokkaido. However, as we explained above, the aestivation of 179
the green sea cucumbers appears in a continuous manner and moreover in stages because of the continuous period of high 17.5 - 19.0°C or higher water temperature and because the maximum temperature is reached during this period. It is therefore expected that in Hokkaido where the period of continuous high water temperature is short, it will not be so easy to perceive clearly the aestivation phenomenon.

In this connection, we will refer to the analytical results obtained by Tanikawa et al (1955) for the Hokkaido green sea cucumber somatic components. Fig. 86 shows the seasonal variations in the proportion (%) of protein nitrogen volume vs. total nitrogen volume. One notes immediately conspiciously low values in June, July, August. There

might seem also to be some relationship with the spawning season but the data speak of somatic component consumption during the high water temperature period. Tanaka also (1958) compared with the July, November and December volumes ingested by green sea cucumbers of the Funka Bay in Hokkaido and suggested the existence of a period corresponding to aestivation.

It was demonstrated that the elimination of body moisture is one of the remarkable physiological modifications taking place during the aestivation of the reptiles (Prosser, 1952). In green and red sea cucumbers also one observes obvious moisture elimination during the aestivation period. The analytical results regarding the somatic components of the green sea cucumbers from Atsumi, Aichi Prefecture show 180
values very similar to the results obtained for the green sea cucumbers from Hokkaido (Tanikawa et al. 1955). More particularly, the crude fat, total nitrogen amounts in the somatic components of the green and of the red sea cucumbers show annual cycle characteristics in which one notes a close relationship with the variations in the amount of body moisture. They increase during aestivation and drop sharply in the recovery period.

So, the water temperature is a factor playing an important role in the ecology of the green and of the red sea cucumbers. The period of continuous water temperature at or above the critical water temperature and the highest water temperature being reached during this period are also related to the annual amount of growth by the sea cucumbers in the same area, and seem also to constitute an important element determining the geographical distribution of the sea cucumbers.

More numerous types of sea cucumbers live in the tropical sea temperature zone and in the frigid sea areas, and we do not know at all whether those species undergo aestivation. It would be very useful to know this in order to understand the phyletic line of the sea cucumbers. The aestivation phenomenon indicates that the green and the red sea cucumbers are sea cucumbers adapted to warm and to cold sea areas.

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Fig. 81 - The photograh of the incised scar on the dorsum (arrow direction) of the green sea cucumber after 248 days of the operation.

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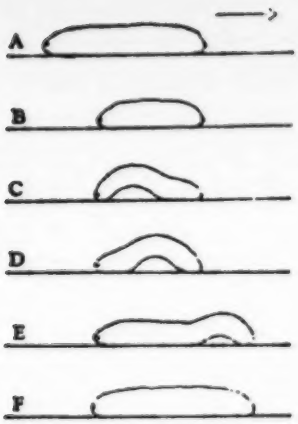

Fig. 82 - Diagrammatic figures of locomotion in the green and the red sea cucumber.

Table 41 - Locomotive velocities of the green sea cucumber. 169

個体番号 Individual No.	匍匐距離 Distance (cm)	所用時間 Time (sec)	1時間当りの匍匐距離 Creeping dist. per hour (cm)	1日当りの匍匐距離 Creeping dist. per day (m)
1	10	72.5	496.6	119.2
2	19	136.0	502.9	120.7
3	24	123.0	702.4	168.6
4	28	144.0	709.9	170.4
5	39	232.5	603.8	144.9
6	39	210.0	668.6	160.5
7	40	258.0	558.0	133.9
8	42	252.0	600.0	144.0
9	48	318.0	543.4	130.4
10	49	391.0	451.2	108.3
平均 Mean			583.7	140.1

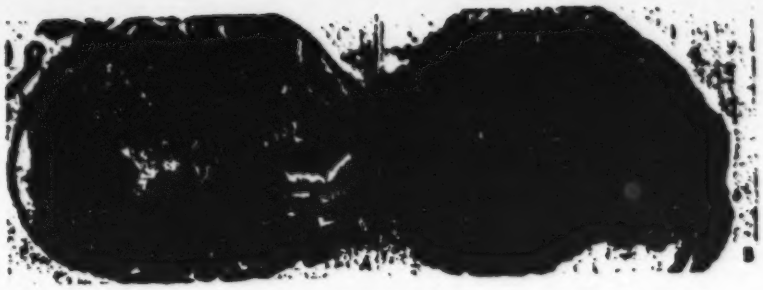

Fig. 83 - Transverse sections of the degenerated alimentary canal of the red sea cucumber. The thickest part of the alimentary canal was more or less 1 millimeter. A : First small intestine. B : Large intestine.

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Table 42 - Degeneration and recovery of the alimentary canal in the green and the red sea cucumbers

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調査日 Date / 採所 Habitat / 摂餌状態 Condition of feeding	1958, Ⅲ, 16—19		1958, Ⅸ, 16—22		1958, X, 15—19		
	低潮帯 Lower tide zone	沖合 Off shore	低潮帯 Lower tide zone	沖合 Off shore	低潮帯 Lower tide zone	湾内 Eel grass zone	沖合 Off shore
消化管容量の100%摂餌 Full with food	17(13.4)*	8(18.2)	2(1.6)	2(4.0)	19(86.4)	63(77.8)	7(21.2)
消化管容量の70—80%摂餌 70—80% filled	18(14.2)	13(29.5)	10(8.2)	10(20.0)	0	0	0
消化管容量の50—60%摂餌 50—60% filled	12(9.4)		12(9.8)		0	0	0
消化管容量の30—40%摂餌 30—40% filled	9(7.1)		14(11.5) 1 (6.7)		0	0	0
消化管容量の10—20%摂餌 10—20% filled	15(11.8)		23(18.9) 2(13.3)		0	0	0
わずかに摂餌する，消化管退化 Feed slightly ; degenerated gut	0	0	0	0	3(13.6)	7(8.6)	3(9.1)
摂餌なし Empty ; degenerated gut	22(17.3)	0	16(13.1) 2(13.3)	33(66.0)	0	11(13.6)	23(69.7)
消化管は赤い糸状に退化 Gut degenerated as like a fine thread	34(26.8) 16(100)**	23(52.3)	45(36.9) 10(66.7)	5(10.0)	0	0	0
計 Total	127 16	44	86 15	50	22	81	33

* 尾数，( ) 内は% Individual numbers. Numbers in the parentheses are %.

** ——：アカナマコを示す ——: represent the Red.

Table 43 - Monthly changes of the proximate composition of the body wall in the green and the red sea cucumbers 174

月 日 Date	カラ Body wall (%)				消化管 Alimentary canal (%)			
	水分 Moisture	全窒素 Total-N	粗脂肪 Crude fat	灰分 Ash	水分 Moisture	全窒素 Total-N	粗脂肪 Crude fat	灰分 Ash
1956, IV—24	*92.70	0.63	0.52	2.66	83.96	1.40	1.73	2.29
	**91.34	0.73	0.42	2.71	84.44	1.50	1.59	2.16
V—22	90.48	0.72	0.52	3.26	86.41	1.40	1.74	2.68
	89.49	0.87	0.59	3.25	84.85	1.56	1.44	2.72
VI—26	87.67	1.02	0.89	2.99	82.32	1.49	1.49	2.31
	88.50	0.91	0.80	3.00	86.34	1.84	1.64	2.02
VII—20	90.29	0.90	0.61	2.80	86.34	1.31	1.28	2.30
	87.30	1.08	0.97	2.95	86.79	1.21	1.26	2.34
VIII—21	88.66	0.94	0.81	3.20	85.23	1.62	1.60	2.78
	85.12	1.43	1.23	3.11	–	–	–	–
IX—25	90.44	0.91	0.59	2.58	–	–	–	–
	89.03	1.12	0.66	2.54	–	–	–	–
XI— 7	92.57	0.53	0.22	2.91	87.31	1.19	1.29	2.05
	92.29	0.56	0.24	2.97	90.30	1.08	0.63	1.58
XII—26	92.28	0.66	0.09	2.97	84.80	1.33	1.24	1.82
	91.24	0.72	0.16	2.89	90.23	1.37	1.27	2.16
1157, II— 6	91.83	0.71	0.32	2.98	85.45	1.39	1.37	2.00
	91.20	0.74	0.39	3.07	87.02	1.45	1.41	1.94
III—18	–	–	–	–	83.70	1.41	1.73	2.27
	–	–	–	–	84.23	1.59	1.58	2.15
平均 Mean	90.77	0.78	0.51	2.93	85.06	1.40	1.47	2.28
	89.48	0.91	0.61	2.94	86.77	1.44	1.35	2.13

* 第1列はアオナマコ Values of the first row represent the Green.
** 第2列はアカナマコ Values of the second row represent the Red.

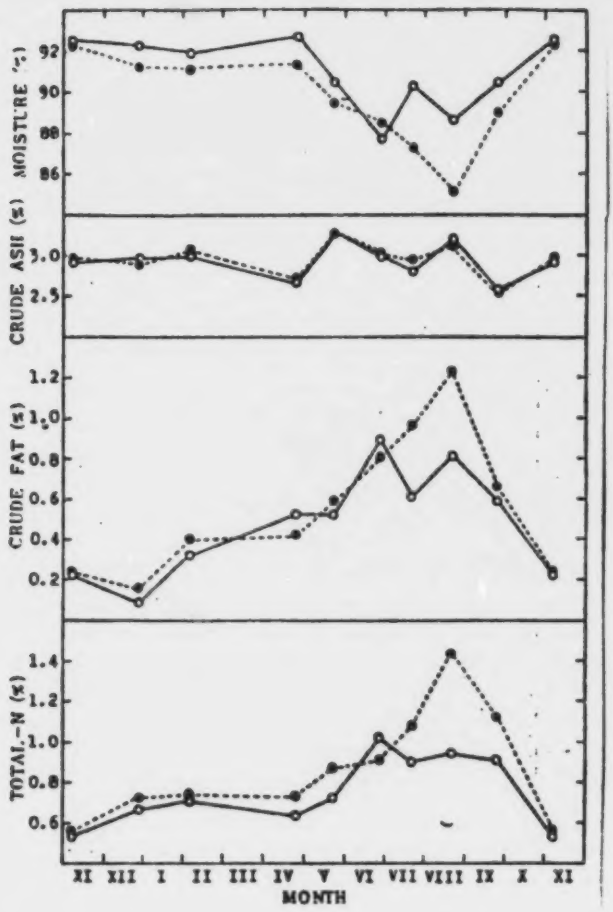

Fig. 84 - Monthly changes of the proximate composition of the body wall in the green and red sea cucumber.
-o-: The green sea cucumber.
-•-: The red sea cucumber.

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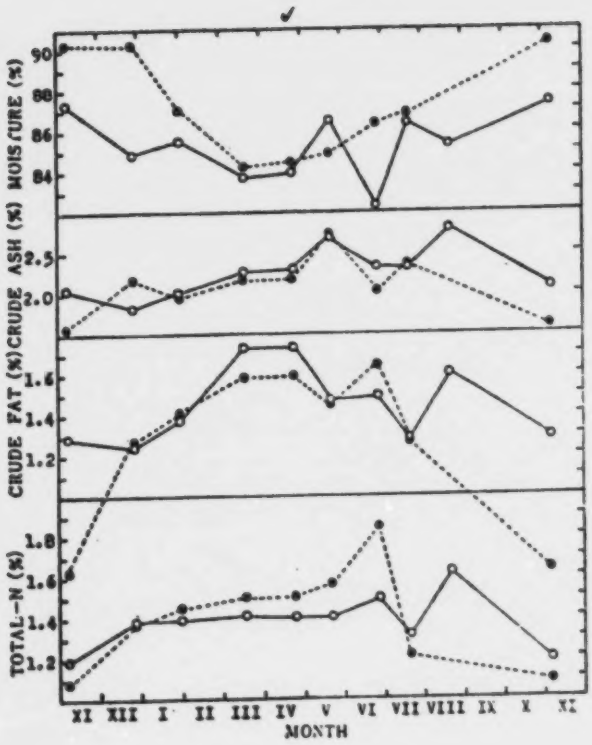

Fig. 85 - Monthly changes of the proximate composition of the alimentary canal in the green and the red sea cucumber.
-o-: The green sea cucumber.
-•-: The red sea cucumber.

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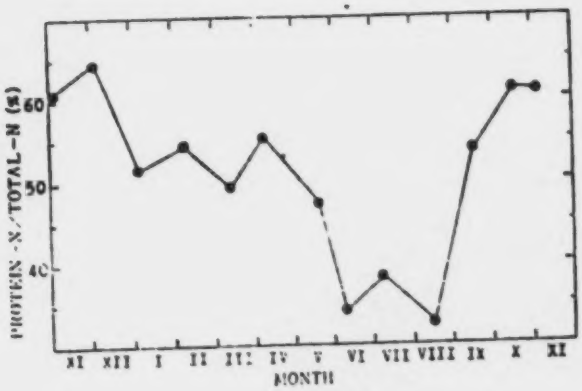

Fig. 86 - Monthly change of the % of protein-N in relation to total-N of the green sea cucumber at Hokkaido (after Tanikawa et al., 1955).

Part III - Studies on the propagation of the green and the red sea cucumbers 181

Introduction

Kaisen, dried abalone and shark fins called the three straw-bagged goods were from old important items in overseas trade, and the demand for the same goods was high. It is said that the Tokugawa Shogunate used to impose sea cucumber contracts on the fishing villages and to exact deliveries so that the village heads had a hard time trying to boost production. Possibly, because of this, one has from ancient times established restricted fishing times and places and advocated rotating harvest methods as means and methods of increasing the production of sea cucumbers. On the Oki island, Shimane Prefecture, one was already practicing by 1800 sea cucumber multiplication based on rock dumping. Later from around 1880, one practiced multiplication in Aza-minato, Muroki* Village, Yamaguchi Prefecture by releasing sea cucumber fry in the ajimo zone inside the bay (Report from the Japanese Fisheries Society, No. 9 - 10) and Sasaki (1896) performed surveys to find sites suitable to the multiplication of sea cucumbers in the Toyohama Village, Aichi Prefecture. Komei* (1896) reported on the sea cucumber multiplication results achieved by dumping rocks in the Oura bay, Saga Prefecture. Kikuchi (1937) reported on the effect of dumping rocks and bundles of branches upon seed collection and multiplication in the Sonogi village area, Nagasaki Prefecture.

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*Translator's note: Reading probable but not entirely certain; same hereafter.

To multiply sea cucumbers, one has later successively established times and areas of restricted fishing, and used methods such as rotating harvesting, dumping brushwood, rocks and the like. The reports from the experimental fisheries stations of the Kanto administration and of all provinces such as Nagasaki, Saga, Fukuoka, Yamaguchi, Hyogo, Kagawa, Ishikawa, Mie, Aichi, Miyagi refer to numerous such multiplication activities.

If we take a general view of the sea cucumber multiplication works carried out so far by the experimental fisheries stations of the various provinces, we see many cases in which the aims were to multiply sea cucumber fry and to increase the weight of the sea cucumbers by releasing seed sea cucumber (parent sea cucumbers in numerous cases) and dumping simultaneously rocks or brushwood. However, except for 2 - 3 instances the results did not generally meet the expectations. One may say that the reason was insufficient knowledge of the sea cucumber ecology.

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This is why, basing ourselves on the ecological characteristics of the green and the red sea cucumbers explained in Part II, we will examine the sea cucumber multiplication methods used in the past and explain the results obtained from studies on multiplication methods making a more particular use of growth and regeneration.

Chapter 1 - Effect of artificial stone shelters for the sea cucumbers

Dumping stones has for a long time been the classic method of multiplying sea cucumbers. On the basis of long-lasting experience, it has generally been accepted among the operators that similarly to fish which flock together in built shelters, sea cucumbers throng in structures made from dumped rocks. Such constructions were part of the fisheries production plans in coastal waters and represent one of the multiplication means utilized from ancient times.

The fact that fish flock together in piled-up rocks has been confirmed by the decisive tests conducted by Oshima (1948). However, no attempts whatsoever have been made to perform tests about how sea cucumbers behave in response to dumped rocks.

If the sea cucumbers had the habit of thronging in dumped rock structures, they would certainly show glimpses of such habit inside small water tanks. Furthermore, if dumped rock structures played an important role in the flocking together of sea cucumbers, one might expect to see some changes in the state of dispersion of sea cucumbers put inside rock pile structures.

From this viewpoint, we built inside water tanks small stone structures, using new gravel or natural stones to which algae were attached, and we performed tests about the reaction by green and by red sea cucumbers to the dumped rocks, the feeding conditions being the presence or

the absence of bottom sediments. We set up simultaneously in natural fishing grounds crawls provided with holes of a size such that sea cucumbers could enter and exit freely, and examined the state of sea cucumber dispersion depending on the presence or absence of dumped rocks inside the crawls. We explain hereafter the tests results as well as the results obtained by discussing the ecological signification of dumped rocks to sea cucumbers.

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Methods

We divided the bottom of a concrete water tank having a 181 cm x 181 cm bottom area and a water depth of 30 cm into 25 equal parts and allowed water to run during the test period. We dumped rocks in the middle section on in one of the 4 corner sections and released sea cucumbers in the same sections, and recorded the sea cucumber distribution at each moment of every observation time. 183

In some cases, we spread no bottom sediment and in some others we spread sand. To build the shelters, we combined three-dimensionally new split granite rocks or 3 - 4 natural stones of the same size to which algae were well attached so as to have stone shelters of a 25 cm x 30 cm -- 35 cm x 40 cm (capacity : about 4 - 6 L) size.

The tests were conducted from March 10, 1960 to April 30. We used sea cucumbers with body wall weights of 15 - 50 g gathered on the beach and from the seaweed fields of the same place, and utilized them

as test material within the 5 days following collection. We used 15 green and 15 red sea cucumbers in the tests I - V, the total number of individuals being 30. In the other tests we used 30 green sea cucumbers.

To know the state of escape of sea cucumbers depending on the presence or absence of a stone shelter inside a crawl, we built in two appropriate places inside the bay crawls made of split bamboo with bottom areas of 100 cm x 50 cm and heights of 25 cm. We divided the crawls with a board in the middle, opened in the vertical surfaces rectangular windows 3.5 cm x 5 cm in size and made it possible for the sea cucumbers to enter or to exit freely (Fig. 88). We put a stone shelter in one side of the crawl but not in the other. We placed in these sections sea cucumbers 184
while varying their numbers, and examined the number of sea cucumbers remaining after a given period of time.

Results

A - Response patterns to the artificial stone shelter in the green and the red sea cucumbers in the case of absence of bottom sediments

We recorded at each observation time the distribution of the sea cucumbers in the water tanks according to the 25 sections of equal size. As shown in Fig. 87, we arranged the results according to 6 sections (A - F) of equal location value. This means that we call A section the sections at the four corners, B sections the 8 sections along the walls next to the A sections, C sections the 4 sections in the middle of the walls, F section

the one section at the center of the tank, D sections and E sections the respective 4 sections at the corners and on the sides of the F section.

To indicate the uniform distribution percentages of the sea cucumbers remaining at the various observation times inside the A - F sections and in the section with the stone shelter, we calculated the proportion of the sea cucumbers remaining in the unit section with regard to each section and expressed in percentage.

We consolidated in Fig. 89 the results obtained concerning the behaviour and response of the green and the red sea cucumbers towards the stone shelter with no bottom sediments.

Test I We put 15 green and 15 red sea cucumbers, the total being 30 individuals in the section F at the center of the tank. The introduced sea cucumbers dispersed immediately in four directions. After 20 - 25 min. they reached the walls in random directions after which most sea cucumbers kept crawling around the walls of the tank.

In daytime, numerous individuals stayed along the walls of the tank, and more particularly in the A sections. The proportions reached 45 - 67% (average : 59%) for the green sea cucumbers and 50 - 96% (average of 74%) for the red sea cucumbers.

At night, the percentage of stay in the A sections was 35 - 74% (46%) for the green cucumbers and 26 - 72% (54%) for the red sea cucumbers

which is lower than in daytime. More particularly, the green sea cucumbers left often the peripheral area advanced to the D, E, F sections during the night. More activity is seen at night. During daytime on the next day the percentages of individuals increased again in the A sections.

Thus, the sea cucumbers placed in the water tank gather in daytime mostly in the sections A, B, C at the periphery of the tank. The concentration is particularly high in the sections A of the four corners. At night however the activity increases, and there is dispersion to every 185
section. The daily changes show repeated gathering along the walls in daytime on the following day. During daytime as well as at night the degree of concentration in the A sections of the four corners was more marked among the red sea cucumbers.

Tests II - III For the Test II we built in section F a stone shelter made from new cut stones. For Test III, we built in the same section a stone shelter with natural stones to which algae were attached. Thereafter we put the sea cucumbers in the stone shelter section.

The proportion of sea cucumbers remaining in the stone shelter section was with regard to the new-stone shelter in daytime 55 - 84% (74%) for the green sea cucumbers and 92 - 96% (94%) for the red sea cucumbers. At night, the percentages were respectively 0 - 65% (36%) and 0 - 95% (40%), showing numerous individuals leaving the stone shelter section at night. With the new stone shelter, no individuals having left the stone shelter section returned to the same section on the next day in daytime.

With the stones having seaweeds attached, both the green and the red sea cucumbers remained clearly gathered inside the stone shelter, regardless of daytime or night.

Tests IV - V For Test IV, we built a shelter with new stones in one of the A sections where the sea cucumber stay rate is high. For Test V, we used stones having seaweeds attached. We put the sea cucumbers in section F at the center of the tank.

In Test IV the sea cucumbers put in sectin F dispersed gradually and a great percentage of individuals reached the stone shelter section. The rate of stay in the stone shelter section was in daytime 19 - 49% (35%) for the green sea cucumbers and 49 - 74% (66%) for the red sea cucumbers. The rates dropped somewhat at night for both the green and the red sea cucumbers. However, on the next day in daytime, the stay rates were again 83 - 89%. Most of the sea cucumbers gather in the stone shelter section.

In Test V, the daytime stay rate of the sea cucumbers in the stone shelter section is 20 - 28% (23%) for the green sea cucumbers and 53 - 65% (60%) for the red sea cucumbers which shows somewhat low values.* At night the amount of activity increases as well as the stay rate in the stone shelter section. In daytime on the next day, almost all sea cucumbers throng in the stone shelter section.

*Note: The sea cucumbers of Test V were used 5 days following their collection so that their active power seemed to have dropped somewhat. Many of the individuals dropped at the center of the water tank, remained at the same position in daytime but started to move in the evening.

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B - Response patterns to the artificial stone shelter among the green sea cucumbers with or without bottom sediment

The Tests VI - XII were conducted solely with green sea cucumbers 188
and we examined the response to stone shelters without bottom sediment or with sand sediment. We used 30 individuals for each test. We conducted the tests several times. As the same tendencies appeared, we give the results in average values. These results are given in Fig. 90.

Test VI We placed the sea cucumbers in the section F at the center of the tank and observed the state of dispersion. We saw the same tendency as in Test I, that is, the stay rate was good in the peripheral parts and more particularly in section A. There was more activity at night.

Test VII We built a stone shelter with new stones in section F and put the sea cucumbers in the stone shelter section.

In daytime, the sea cucumber stay rate in the stone shelter section was 63 - 92% (84%) without bottom sediment, and 54 - 87% (67%) with sand bottom sediment, the former rate being thus higher. At night dispersion occurs and the stay rate in the stone shelter section is 0 - 58% (19%) without sediment and 14 - 46% (28%) with sand bottom sediment, the latter rate being higher. On the next day in daytime, the stay rate increases again in the stone shelter section. However, it is 24 - 37% (31%) for sand bottom sediment whereas it is 13 - 22% (18%) without bottom sediment, the former rate being thus higher.

Test VIII We built with new stones a shelter in one single A section, and put the sea cucumbers in the stone shelter. In daytime, most sea cucumbers stayed in the stone shelter regardless of the absence of bottom sediment or presence of sandy bottom sediment. We noted dispersion at night. On the next day in daytime, 77 - 95% of the sea cucumbers thronged again in the stone shelter.

Test IX We built a stone shelter in one single A section and placed the sea cucumbers in section F. They dispersed gradually and reach the peripheral parts. There is a clear difference in stay rates in the stone shelter sectin during daytime and night.

Tests X - XII We built in section F or in one single section A a shelter with natural stones to which algae were attached and placed the sea cucumbers in the stone shelter section or in the F section.

In these tests also and more particularly in daytime, most sea cucumbers stay in the stone shelter section. We observe some dispersion at night. On the following day in daytime, the sea cucumbers throng again in the stone shelter section, and so are clearly revealed diurnal cycle characteristics. A comparison with Tests VII, VIII, IX in which stone shelters are built with new stones shows that the sea cucumber stay rates vary greatly in the stone shelter section depending on the presence or absence of stone materials with algae attached. In all tests, one may consider that there are virtually no differences in the response by the sea cucumbers to the stone shelters depending on the presence or absence of bottom materials.

C - Escape of the green sea cucumbers from crawls provided or not provided with a stone shelter 189

As the density of the sea cucumbers held in the crawl rises, they escape more actively from the crawl. We installed in natural fishing grounds crawls provided with windows through which the sea cucumbers could enter or exit freely, put sea cucumbers at various densities inside the particular crawls and examined the staying of the sea cucumbers inside the crawls according to the presence or absence of a stone shelter.* The results are shown in Tables 44, 45.

Among the sites for crawl installation seen in Table 44 the best environment to rear sea cucumbers is Yarigasaki. One cannot say that the bay inside and the seawater ponds are so good. No difference is noted in the number of staying sea cucumbers depending on the presence or absence of a stone shelter inside the bay and inside the seawater ponds. After 27 - 44 days, the number of individuals settled at 0 - 4 (average of 1.6 individual) regardless of the initial accommodation density. Meanwhile, at Yarigasaki, the number of staying individuals after 44 - 73 days in the stone shelter section was 1 - 7 (average of 2.6). It was 0 - 3 (0.9) in the section without stone shelter. The staying proportion is evidently higher in the stone shelter section.

Table 45 shows the results obtained by placing 5, 10, 20, 40 green sea cucumbers in each section of crawls installed inside the bay, and by examining the stay rates after 1, 3, 14 and 45 days.

*Note: A shelter made by piling up 3 - 4 stones 25 cm x 15 cm in size and with a volume of about 2 L.

The rate of sea cucumber escape out of the crawls from the time the sea cucumbers had been placed in crawls of determined surface area increases together with the accommodation density. As the results demonstrate, the stay rate in the stone shelter section is greater than in the section without a stone shelter. In the July 9 (45th day) survey, the number of sea cucumbers was greater than at the time of the previous survey. Many of the sea cucumbers which had escaped from the crawls penetrated however cracks between the crawls and the sea bottom. This shows that with the rise of water temperature in July they had sought a place for aestivation and had later come back inside the crawl. The bottom board of the crawls containing a this time 40 individuals had broken up, and this is why the sea cucumber increase was greater than in the other crawls.

Discussions

The results of the above tests and discussions show clearly that 190
the sea cucumbers avoid light inside water tanks, and that they proceed by touch which makes them gather in those unit space parts of the tank periphery where the touch surface is greatest, and more particularly in the four corners.

The green and the red sea cucumbers show in their responses a definite affinity with stone shelter installations. In shallow water tanks where there is a direct alternate action of the brightness and the darkness of day and night, the behaviour of the sea cucumbers shows diurnal cycle characteristics. In daytime, the sea cucumbers gather at the periphery of

the tank or in the stone shelter installation and are little active. They are active at night. One may say that such evident characteristics of thronging to the stone shelters in daytime indicate that the stone shelter installations play for the sea cucumbers the role of a place of refuge. The red sea cucumbers show the strongest tendency to throng in stone shelter installations. However the value of stone shelter as a sea cucumber refuge differs according to the feeding conditions of the sea cucumbers themselves. Although not too likely to occur under natural conditions, one may think that the refuge value of stone shelter installations is rather small for hungry sea cucumbers (Tests II, VII).

The stay rates of sea cucumbers are always better with stones to which algae are attached than with new stones. It is unclear whether some element related to feeding conditions is at work here or whether such stones provides some other advantageous condition. The same is true when bottom sediment is provided and the feeding conditions are more or less satisfied. As explained in the chapter on diet, the green and the red sea cucumbers feed continuously so that it is understandable that a greater affinity is shown for stone shelter installations providing feeding elements.

As to the reason why fish gather around structures, Goto (1935) and Kusakabe (1936) mention the habit of fish to congregate in the shadow of objects and refer also to the food produced by these structures. Oshima (1948) however believes that the habit in fish of gathering in the shadow of objects, that is the element of responding or acting in an orientated fashion to "places" such as structures is a primary reaction, and that the feeding element is rather secondary.

As aforementioned, the green and the red sea cucumbers held in a water tank show a clear tendency to shy away from light and to gather densely at the periphery of the tank. As the gathering is particularly pronounced at the four corners, one may say that the sea cucumbers exhibit clearly sensory characteristics.

Furthermore, the dispersion of the sea cucumbers dropped in the middle of the tank shows no particular orientation. If, pursuing their course, they encounter places such as stone shelters or some other objects, it seems that they will throng in such places because of their avoidance of light and because of their sensory type of responses. If feeding 193
conditions are also provided, one may think that thronging will become continuous.

One sees that on a sea floor where a stone shelter is brighter than the dark floor or that on sea floors of a bright colour, it is effective to provide areas suited to the ecology of the sea cucumbers.

With regard to the effect of the sole stone shelters upon sea cucumber multiplication, it does not appear that all practical data have been gathered. Actually, this is a difficult problem. Building sone shelters on ecologically suited beaches has evident bearing on the multiplication of sea cucumber fry. Yet, even if stone shelters built in deeper places may conceivably be momentarily more appropriate sites for sea cucumber concentrations, it is however totally impossible to know how this is related to sea cucumber spawning generation or with aestivation and how this would directly lead to sea cucumber multiplication. Moreover, it

would costwise be rather prohibitive. Nevertheless, the presence of stone shelter installations would protect the sea cucumbers from too effective fishing gear such as beam trawls and would, it seems, play some role in the conservation of stocks. One may however say that building mainly in the relatively shallow places of the low-tide zone stone shelters intended for sea cucumber multiplication and that fostering an environment conducive to attachment by sea cucumber fry is in an ecological respect the most suited method.

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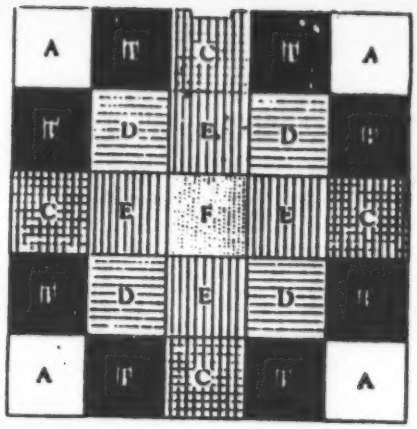

Fig. 87 - Sections of the tank used for behavioural experiments of the artificial stone shelter.

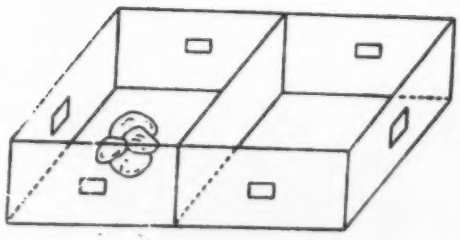

Fig. 88 - Structure of the store box used to the experiment of escape for the green sea cucumber.

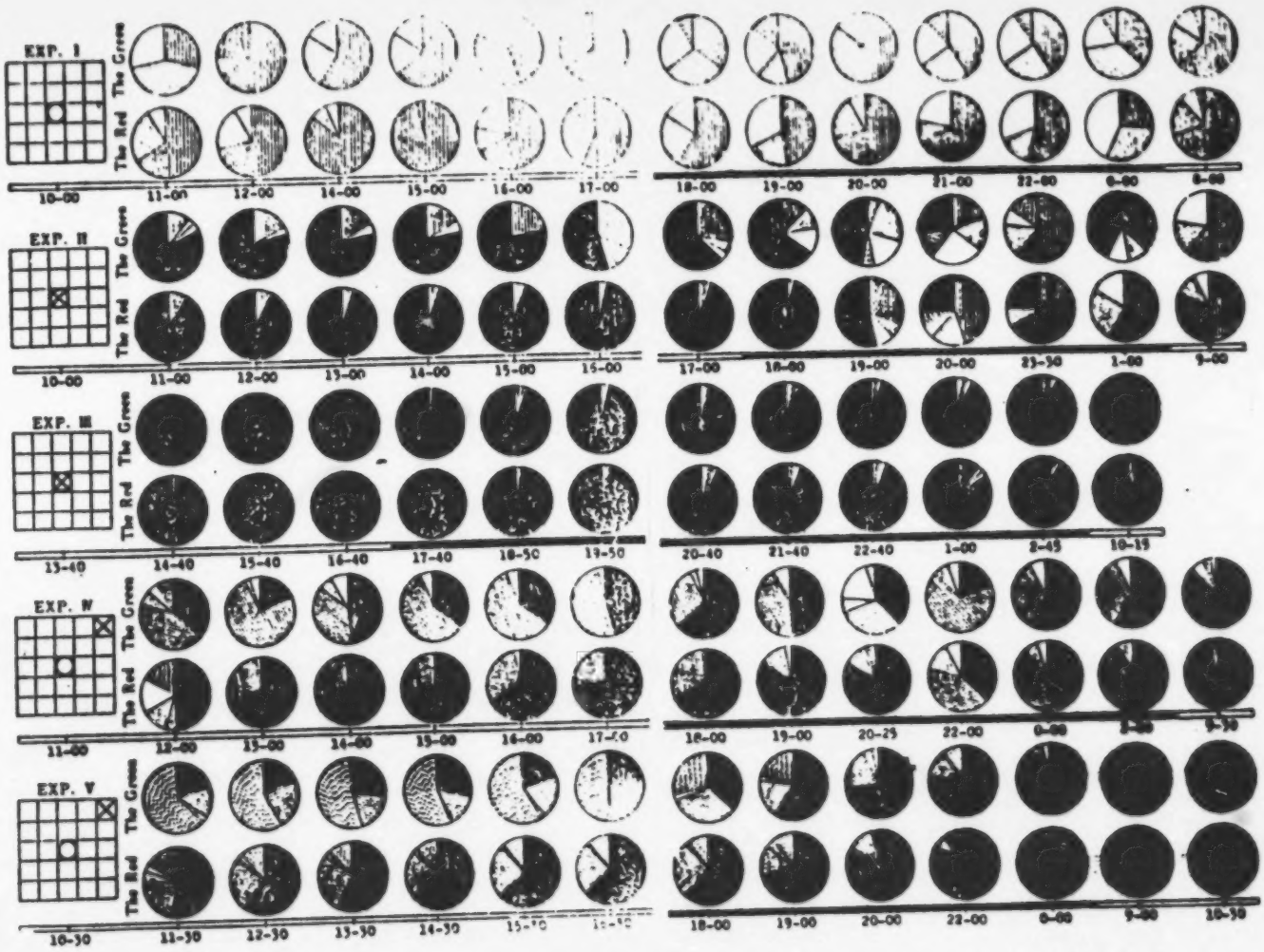

Fig. 89 - Schematic representation of responses (in terms of distribution of the sea cucumber in the tank) to the artificial stone shelter in the green and the red sea cucumber in the case of absence of bottom sediment. In left figures, o and x denote the initial location of the sea cucumber and the stone shelter, respectively.

Section C. Section D, E,

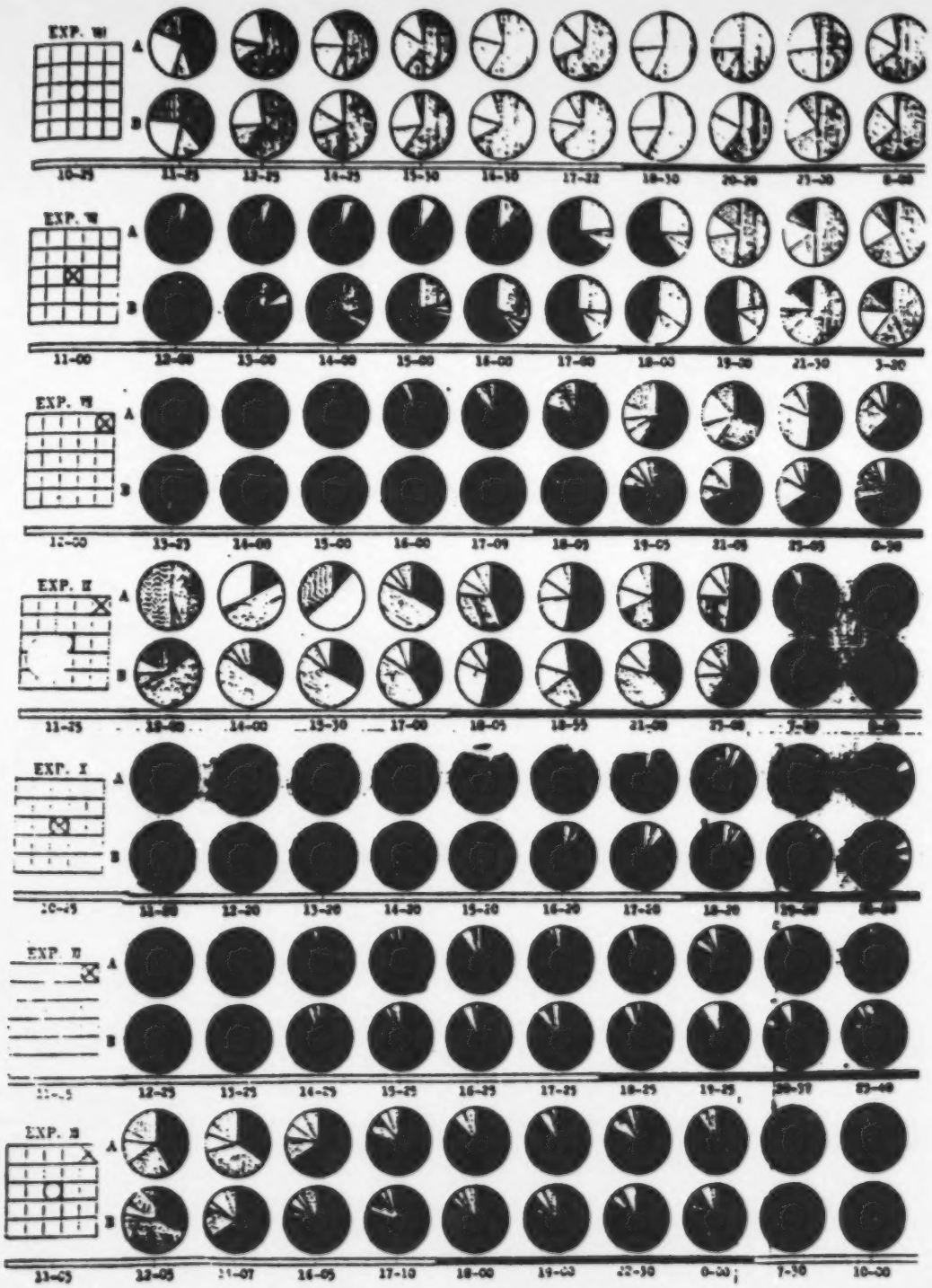

Fig. 90 - Schematic representation of responses (in terms of distribution of the sea cuc stone shelter in green and the red sea cucumber with (B) or without (A) denote the initial location of the sea cucumber and the stone shelter respectively.

O and x Section A . Section B . Section C Section D, E, F

Table 44 - Escape of the green sea cucumber with the artificial stone shelter provided or not in the store box at three stations. 190

*	**	2		4		8		16		32		実験期間
Series of exp.		無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	Periods of experiments
Sand	I	-	-	1 (50.0)	0	1 (12.5)	2 (25.0)	3 (18.8)	2 (12.5)	2 (6.3)	2 (6.3)	III-15～IV-28 (44日)
	II	1 (50.0)	0	0	1 (25.0)	0	2 (25.0)	4 (25.0)	3 (18.8)	-	-	IV-28～V-25 (27日)
Mud	I	-	-	0	1 (25.0)	0	2 (25.0)	1 (6.3)	2 (12.5)	2 (6.3)	2 (6.3)	III-15～IV-28 (44日)
Muddy sand	II	0	2 (100.0)	0	2 (50.0)	1 (12.5)	7 (87.5)	3 (18.8)	5 (31.3)	-	-	IV-28～VII-10 (73日)
	I	-	-	2 (50.0)	0	1 (12.5)	1 (12.5)	2 (12.5)	3 (18.8)	2 (6.3)	2 (6.3)	III-15～IV-28 (44日)

( ) 内の数字はナマコの滞留率 Numbers in the parentheses represent the rate of stay in the section.
* 収容尾数 Accommodated numbers of the cucumber.
** 投石の有無 Division of the section.
*** 底質の性状 Bottom property.

Table 45 - Escape of the green sea cucumber with the artificial stone shelter provided or not in the store box.

*	**	V-26 (1 day)		V-28 (3 days)		VI-8 (14 days)		VII-9 (45 days)	
***		無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone	無投石 No stone	投石 Exist stone
5		3 (60.0)	5 (100.0)	3 (60.0)	3 (60.0)	1 (20.0)	2 (40.0)	1 (20.0)	3 (60.0)
10		7 (70.0)	6 (60.0)	3 (30.0)	5 (50.0)	2 (20.0)	1 (10.0)	4 (40.0)	3 (30.0)
20		9 (45.0)	12 (60.0)	4 (20.0)	8 (40.0)	4 (20.0)	2 (10.0)	3 (15.0)	7 (35.0)
40		13 (32.5)	13 (32.5)	4 (10.0)	7 (17.5)	3 (7.5)	5 (12.5)	7 (17.5)	10 (25.0)

( ) 内の数字はナマコの滞留率を示す。 Numbers in the parentheses represent the rate of stay in the section.
* 経過日数 Lapse of day.
** 投石の有無 Division of the section.
*** 収容尾数 Accommodated numbers of the cucumber.
**** 小箱の底板がこれである。 The bottom plate of the store box was [illegible].

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Biology of the Japanese common sea cucumber, *Stichopus japonicus* Selenka

Sang Choe

Part I. Taxonomical studies.

1. The Japanese common sea cucumber, *Stichopus japonicus* is divided into three forms due to the body color, the Green, Red and Black. Of these three, the former two are important, through they have a different market value. As for the taxonomy of this species, there are *Stichopus japonicus* and *Holothuria armata* described by E. Selenka (1867); *S. japonicus* var. *typicus* by H. Théel (1886); and *S. armatus* and *S. roseus* by E. Augustin (1908). K. Mitsukuri (1897) and H. Ohshima (1918) made it clear that these were all but synonyms of the *S. japonicus* and this remains still accepted. The two forms of the Green and the Red, on the other hand, were first reported by K. Mitsukuri (1912) and were ascribed by the same author to a color variation due to the difference in habitat and thereafter his opinion has been widely accepted by the investigators. Between these two forms, however, there are found some distinct differences, not only morphological but also ecological.

2. The predominant color of the Green is the dark bluish green, which varies with individuals from light bluish green to yellowish brown or dark brown. The Key tone for the Red is red or brownish red, and the ventrum being in red without exception and to be its characteristic. There are, though very low in their occurrence (no more than 1 to 2 per cent), some intermediate forms with the dorsum similar to the Green and the ventrum similar to the Red, and vice versa.

3. The Polian vesicles of the Green are usually of stumpy shape with dully round tip, while those of the Red are slender with projected tip.

4. The body contractibility of the Red is remarkable and under a mechanical stimulus, for example, it contracts into an almost round shape, while no such habit is observed with the Green.

5. The matured egg of the Red has a gelatinous coating 23—26 microns thick, while the Green has without it.

6. The shape of the ossicles of tentacles is much more complicated in the Red than the Green, whereas the disk of the tables of the former

is more round-shaped and the circumference of its holes in broader than the latter. As for the size of the disk of tables, when compared with individuals of the same body weight, the Green wins over the Red.

7. The Green has a preference to somewhat lower salinity and eventually finds its favorite habitat on sand and muddy-sand grounds, while the Red with fondness for higher salinity lives mainly in the rock, pebble and gravel grounds.

8. Usually, the spawning period of the Red is earli erand shorter than that of the Green.

9. In view of the modes of reaction to the environments, such as growth and adaptation for salinity, the Green and the Red are judged to belong to a different environment, respectively.

10. In summer season when the water temperature is high, almost all of the Red take aestivation, on the contrary 50 per cent of the Green of 6 to 30 g (weight of body wall) and 75 per cent of the grown-up are found in aestivation, and younglings of less than 5 g totally dispence with it.

11. The Green, in general, have strong capability of regeneration than that of the Red.

12. These morphological and ecoloical differences between the Green and the Red are well considered to be suggesting far more than a mere variation, or more precisely, to be constituting a fair ground for establishing a new species.

Part II. Ecological studies.

1. An enquête held for a distribution survey on 1200 geographically spotted localities has revealed that, though these three forms of the sea cucumber distribute all along the coast of Japan, the Green makes its chief habitat on sand or sand-muddy bed near a bay area, and the Red on reef, pebble or gravel bed toward the open sea.

2. Since 1928, the national annual production of the sea cucumbers stands between 6,500 and 9,500 tons. 12 chief production prefectures arranged in a discending order are Hokkaido, Yamaguchi, Ishikawa, Nagasaki, Aomori, Aichi, Hiroshima, Mie, Fukushima, Hyogo, Saga and Kagawa, holding 92.4 per cent in the aggregate over the national total prodution.

3. As for the measurable merits of the Green and the Red, the body length, the volume and the total body weight have little significance, not only because these three merits are accompanied with the respective measurement errors of 4.8—5.1 per cent, 2.9 per cent and 2.0—2.4 per cent.

but also from the very ecological point of view. The author recommends the measurement of the body-wall weight.

4. The relation between the total weight, the volume and the body length of the Green is expressed by an exponental curve, which inflects at the two points each corresponding to the body length of 6.0 cm and 16.0 cm.

5. The relation between the the volume (V cc) and the total weight (TW g) of the Green is, irrespective of the season, expressed in a linear equation, $V = 0.9738\,TW$

6. The relation between the total body weight, the volume and the body-wall weight of the Green is well expressed in a linear equation. The curve inflects at points of 25 g and 70 g of the body-wall weight, corresponding to the seasonal periods.

7. The relation between the amount of coeliac water and the body-wall weight is expressed by a logarithmic curve. The amount of coeliac water for the Green changes between 20 and 85 per cent of the body-wall weight (51.3 per cent in average), while that of the Red is less with a fluctuation between 14 and 51 per cent (31.8 per cent in average).

8. The fishing ground for the Green is found wide around the gravel, sand or sand-muddy area which intervenes between the ebb-tide line and the purely muddy bed in the offing. More favorable a fishing ground is formed where there is, at the back, a good place for setting of the young cucumber and the sea water circulates well.

9 The size of the Green can be distinctively classified according to the depth: the size of body increases with increased water depth. The Red, too, show a similer tendency to this, though its vertical distribution is comparatively limited.

10. Both the Green and the Red are colorless and transparent at their earlier stage, but, with the body length of 14 to 21 mm or with the total body weight of 0.05 to 0.20 g as a turning point, they begin to differ in the point of their body colors. The young of the cucumber lie sticking to the roots of seaweeds or to the stems of the eel-grass, which hold fast on reef or the like, but are not found on places deeper than eel-grass zone or on sand-muddy area. Getting grown up, the Green advances into the sand-muddy area, while the Red disperses no farther.

11. The Red falls behind the Green in the resistance against lower salinity. The adaptable minimum value of salinity is 12.6‰ (in Cl) for the Green and 14.1‰ (in Cl) for the Red.

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11. The Red falls behind the Green in the resistance against lower salinity. The adaptable minimum value of salinity is 12.6‰ (in Cl) for the Green and 14.1‰ (in Cl) for the Red.

12. As for the oxygen consumption, no difference is observed between the Green and the Red, and a logarithmic curve stands for the relation between the oxygen consumption and the weight of body-wall. In the active period of the sea cucumber, the slope of the relevant equation stands at 0.7 to 0.9 at the water temperature of 8.5 to 13.5 °C and at 0.4 to 0.5 at the water temperature of 18.5 to 13.5°C. The percentage which the integumentary respiration holds over the total respiration of the cucumber is estimated at 39 to 52 per cent at the water temperature of 8.5 to 13.5 °C, while suddenly increasing to 60-90 per cent at the water temperature higher than 18.5 °C.

13. The length and weight of the alimentary canal of the Green shows a very regular periodicity in accordance with the seasonal changes in water temperature. The highest and the lowest climax are observed at the lowest water temperature in winter and the highest water temperature in summer, respectively.

14. The yield of Konowata (salted entrails) varies a great deal with periods, whereat the maximum is observed during the period between mid-February and mid-March with 6 to 9 per cent of the body-wall weight. Generally, the yield is larger with smaller individual than with larger one.

15. The life cycle for the Green can be classified into the four phases, namely, the active period, the pre-aestivation period, the aestivation period and the recovery period. The water temperature at the climax of the active period is lower than 8 to 10°C. With 17.5 to 19°C, the sea cucumber enters into the pre-aestivation period, and with 24.5 °C into aestivation. With the decrease in the summer highest water temperature as a stimulus, the sea cucumber enters into the recovery period, and, as the water temperature drops down to 19 or 20 °C, it returns to its active period. The Red, too, repeats a life cycle similar to the Green's.

16. The capacity of the cavity of alimentary canal shows as regular an annual periodicity as the length and weight of the alimentary canal do with the seasonal changes in water temperature: the highest climax is observed in winter, and the lowest climax in summer.

17. The gonad of the Green rapidly develops later than the first decade of March with an approximate sex ratio of 1: 1. The biological minimum size is 58 to 60 gr in body-wall weight. The spawning of the Green starts with a water temperature of 13 to 16 °C and ends up with that of 18 to 22°C. The number of eggs per 1 gr. of mature ovary is 183,000 to

263,000, or 209,000 in average.

18. On the enteron of the Green and the Red, we can distinguish the oesophagus, the stomach, the 1st small intestine, the 2nd small intestine and the large intestine. The young of the Green and the Red up to 2.0-2.5 gr of the body-wall weight are feeding on adhesive micro algae or detritus. On the other hand, the adult are a nonselective deposit feeder. The feeding rate of the Green has no relation to the size of the cucumber. It is tantamount to 0-10 per cent of the body-wall weight in the middle of August, 5-35 per cent of the same early in December and 20-45 per cent of the same early in March. The time required for the digestion is about 21 hours, during which 51 to 57 per cent of the organic carbon and 52 to 54 per cent of the organic nitrogen contained in the diet are digested.

19. In the digestive enzymes of the Green and the Red are detected amylase, cellulase and pectinase as of carbohydrases, and proteinase and dipeptitase as of proteases. As estrases, there are small amounts of enzymes which digest simple ester, glyceride and even the higher fatty acid.

20. The growing of the Green and the Red are observed progressing with a water temperature below 16 to 17°C; the actual growth period is the seven months from November to May. A water temperature higher than 16 or 17°C results in a decrease in the body weight.

21. In a full year, the Green grows up to 9 gr in body-wall weight (body length: 5.9 cm, total body weight: 15.5 gr); in two years, 80 gr (13.3 cm, 122.4 gr); in three years, 175 gr (17.6 cm, 307.1 gr), and in four years, 260 gr (20.8 cm, 472.5 gr).

22. The growth of the Green and the Red has a close relation to the accommodation density: the growth rate decreases with increased density.

23. Both the Green and the Red are strong in their regeneration capability. An incised cut of 2 to 4 cm on the dorsum or abdomen cures in 5 to 7 days and no deaths due to operation have been observed.

24. In case of a cross cutting of a cucumber in the Green and the Red, the regeneration is more rapid at the posterior part than at the anterior part of the body, and the anus and the mouth are regenerated in the respective positions in 63 to 79 days. The survival rate is, both with the anterior and the posterior part, 33 to 92 per cent with the Red, and no higher than 107 per cent even with the Green. In view of the decrease in the body-wall weight due to operation and the actual annual growth, there is quite no utility in the method of cutting for propagation.

25. The rapidity of alimentary canal regenerating varies with seasonal periods and, as during the recovering period, it regenerates itself in 25 to 33 days after the operation into an alimentary canal capable of functional feeding.

26. The incised scar on the dorsum of the Green or the Red is clearly recognizable even after eight months: this affords a possibility of using it as an individual mark, if only for about one year.

27. The creeping speed of the Green in a cistern is 497 to 710 cm (584 cm in average) in an hour. Calculated on this basis, the movement in a day is 108 to 170 m in a straight distance.

28. The critical water temperature at which the Green and the Red positively enter into aestivation is 24.5 °C. During the aestivation, all the feeding is stopped and the alimentary canal gets atrophied into a sort of fine cotton thread.

Part III. Propagational studies.

1. Both the Green and the Red show a reaction being attracted to the stone shelter apparatus equipped in the experimental cistern, though more the Red swarm towards the stone shelter than the Green. In the cistern, the Green and the Red show a negative heliotropism in distributing more around the circumference, and a thigmotaxis in crowding around the corners. A daily periodicity is that they swarm towards a stone shelter in daytime and disperse away from it in night time.

2. A stone with epiphytic seaweeds on attracts more sea cucumber than a clean stone does.

3. When the Green and the Red are thrown into the center of the cistern, they prove astatic of the direction. The conjecture, however, is that, when they happen in their course of direction-astatic movement to come by a "place" where, say, a stone is thrown, they would eventually swarm more around that "place" out of their negative heliotropism and thigmotaxis and, with sufficient feeding condition, this swarmed state would last well and through.

4. The effect of the stone shelter on the cucumber is presumed greater in bright sea bed than in dark bed. The apparatus is to be positioned on such a rather shallower bed as is between the low tide zone and a depth of no more than 2 or 3 m, with emphasis on attracting and fostering the young of cucumber.

5. An expedient to the increased production of Konowata (salted entr-

ails) lies in regenerating of the alimentary canal. When the cucumber is planted within December after ablation of the alimentary canal, the alimentary canal regenerates by the end of March to as large a size as almost equals to that of natural cucumber of the same period.

6. As for the planting of seed cucumber, no great effect would be expected from the supplementary turning loose of the adult cucumber, if it were not hand in hand with building up around the beach zone a reasonable place for the young to stick on. In the case of aiming at the quantity increase, to be turned loose are small cucumber, whose annual growth is large.

7. Ecologically speaking, the Green is more vulnerable to the damage by intense fishing than the Red is. A throughgoing protective measure for the young would result in an unexpectedly higher increase in the production. Disirable is, if possible, to dosignate as closed ground for fishing those area shallower than the eel-grass zone where the young of cucumber live.

8. An expedient to positively propagate the Green is to diligently return loose to the fishing ground the small cucumber whose alimentary canal has been exploited. The author has turned loose living valves of the Green of 6 to 60 gr (25.5 gr in average) of the body-wall weight in June and harvested in February of the next year an increase of more than four times of the weight.